The Measurement of Productivity

In the May 1969 SURVEY OF CURRENT BUSINESS, Part II, BEA published a critique by Edward F. Denison of a study of U.S. productivity change by Dale W. Jorgenson and Zvi Griliches. The Jorgenson-Griliches study, "The Explanation of Productivity Change," was reprinted in that volume. The present volume concludes the discussion between Denison and Jorgenson-Griliches and, for the convenience of the reader, reprints in full the contents of the earlier issue of the SURVEY.

Differences in concepts and methodology used by Jorgenson-Griliches and Denison at the time of the earlier publication led to striking differences in their results. According to Denison, a substantial part of the postwar growth of national output was due to an increase in productivity; according to Jorgenson and Griliches, almost all of the increase was due to an increase in factor inputs.

In "Issues in Growth Accounting: A Reply to Edward F. Denison," Jorgenson and Griliches now assign a much larger role to productivity in the explanation of economic growth, and in several respects have come closer to the concepts and methodology advocated by Denison. But substantial differences remain, and they argue that Denison is using inconsistent procedures in his treatment of capital. Denison's "Final Comment" is a detailed and comprehensive discussion of the basic issues relating to the measurement of capital inputs that divide experts who share the marginal productivity approach to the analysis of output, input, and productivity. In their "Final Reply," Jorgenson and Griliches restate their position.

The present volume will be indispensable to all economists and statisticians who are seriously interested in productivity. BEA is pleased to be able to provide a forum for the discussion between these distinguished experts, and to provide readers the opportunity to make up their own minds on the remaining unsettled issues.

The contents of this volume are as follows

The Explanation of Productivity Change

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and

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Reprinted with corrections from

The Review of

Economic Studies

Vol. XXXIV (3), No. 99

(July 1967)

The Explanation of Productivity Change[1]

But part of the job of economics is weeding out errors. That is much harder than making them, but also more fun.—R. M. SOLOW

1. INTRODUCTION

Measurement of total factor productivity is based on the economic theory of production. For this purpose the theory consists of a production function with constant returns to scale together with the necessary conditions for producer equilibrium. Quantities of output and input entering the production function are identified with real product and real factor input as measured for social accounting purposes. Marginal rates of substitution are identified with the corresponding price ratios. Employing data on both quantities and prices, movements along the production function may be separated from shifts in the production function. Shifts in the production function are identified with changes in total factor productivity.

Our point of departure is that the economic theory underlying the measurement of real product and real factor input has not been fully exploited. As a result a number of significant errors of measurement have been made in compiling data on the growth of real product and the growth of real factor input. The result of these errors is to introduce serious biases in the measurement of total factor productivity. The allocation of changes in real product and real factor input between movements along a given production function and shifts of the production function must be corrected for bias due to errors of concept and measurement.

The purpose of this paper is to examine a hypothesis concerning the explanation of changes in total factor productivity. This hypothesis may be stated in two alternative and equivalent ways. In the terminology of the theory of production, if quantities of output and input are measured accurately, growth in total output is largely explained by growth in total input. Associated with the theory of production is a system of social accounts for real product and real factor input. The rate of growth of total factor productivity is the difference between the rate of growth of real product and the rate of growth of real factor input. Within the framework of social accounting the hypothesis is that if real product and real factor input are accurately accounted for, the observed growth in total factor productivity is negligible.

We must emphasize that our hypothesis concerning the explanation of real output is testable. By far the largest portion of the literature on total factor productivity is devoted to problems of measurement rather than to problems of explanation. In recognition of this fact changes in total factor productivity have been given such labels as The Residual or The Measure of Our Ignorance. Identification of measured growth in total factor productivity with embodied or disembodied technical change provides methods for measuring technical change, but provides no genuine explanation of the underlying changes in real output and input.[2] Simply relabelling these changes as Technical Progress or Advance of Knowledge leaves the problem of explaining growth in total output unsolved.

[1] The authors' work has been supported by grants from the National Science and Ford Foundations.
[2] See Jorgenson [35] for details.

The plan of this paper is as follows: We first discuss the definition of changes in total factor productivity from the point of view of the economic theory of production. Second, we provide operational definitions for the measurement of prices and quantities that enter into the economic theory of production. These definitions generate a system of social accounts for real product and real factor input and for the measurement of total factor productivity. Within this system we provide an operational definition of total factor productivity. This definition is fundamental to an empirical test of the hypothesis that if real product and real factor input are accurately accounted for, the observed rate of growth of total factor productivity is negligible.

Within our system of social accounts for real product and real factor input we can assess the consequences of errors of measurement that arise from conceptual errors in the separation of the value of transactions into price and quantity. Errors in making this separation may affect real product, real factor input, or both; for example, an error in the measurement of the price of investment goods results in a bias in total output and a bias in the capital accounts that underlie the measurement of total input. Within this system of social accounts we can suggest principles for correct aggregation of inputs and outputs and indicate the consequences of incorrect aggregation. Many of the most important errors of measurement in previous compilations of data on real product and real factor input arise from incorrect aggregation.

Given a system of social accounts for the measurement of total factor productivity we attempt to correct a number of common errors of measurement of real product and real factor input by introducing data that correspond more accurately to the concepts of output and input of the economic theory of production. After correcting for errors of measurement we examine the validity of our hypothesis concerning changes in total factor productivity. We conclude with an evaluation of past research and a discussion of implications of our findings for further research.

2. THEORY

Our definition of changes in total factor productivity is the conventional one. The rate of growth of total factor productivity is defined as the difference between the rate of growth of real product and the rate of growth of real factor input. The rates of growth of real product and real factor input are defined, in turn, as weighted averages of the rates of growth of individual products and factors. The weights are relative shares of each product in the value of total output and of each factor in the value of total input. If a production function has constant returns to scale and if all marginal rates of substitution are equal to the corresponding price ratios, a change in total factor productivity may be identified with a shift in the production function. Changes in real product and real factor input not accompanied by a change in total factor productivity may be identified with movements along a production function.

Our definition of change in total factor productivity is the same as that suggested by Abramovitz (1), namely, "... the effect of 'costless' advances in applied technology managerial efficiency, and industrial organization (cost—the employment of scarce resources with alternative uses—is, after all, the touchstone of an 'input') ..." [1] Of course, changes in total factor productivity or shifts in a given production function may be accompanied by movements along a production function. For example, changes in applied technology may be associated with the construction of new types of capital equipment. The alteration in patterns of productive activity must be separated into the part which is "costless", representing a shift in the production function, and the part which represents the employment of scarce resources with alternative uses, representing movements along the production function.

[1] Abramovitz [1, p. 764].

On the output side the quantitites that enter into the economic theory of production correspond to real product as measured for the purposes of social accounting. Similarly, on the input side these quantities correspond to real factor input, also as measured for the purposes of social accounting. The prices that enter the economic theory of production are identified with the implicit deflators that underlie conversion of the value of total output and total input into real terms. The notion of real product is a familiar one to social accountants and has been adopted by most Western countries as the appropriate measure of the level of aggregate economic activity. The notion of real factor input is somewhat less familiar, since social accounting for factor input is usually carried out only in value terms or current prices. However, it is obvious that income streams recorded in value terms correspond to transactions in the services of productive factors. The value of these transactions may be separated into price and quantity and the resulting data may be employed to construct social accounts for factor input in constant prices. This type of social accounting is implicit in all attempts to measure total factor productivity.

The prices and quantities that enter into the economic theory of production will be given in terms of social accounts for total output and total input in current and constant prices. We observe that our measurement of total factor productivity is subject to all the well-known limitations of social accounting. Only the results of economic activities with some counterpart in market transactions are included in the accounts. No attempt is made to measure social benefits or social costs if these diverge from the corresponding private benefits or private costs. Throughout this study we adhere to the basic framework of social accounting. The measurement of both output and input is based entirely on market transactions; all prices reflect private benefits and private costs. That part of any alteration in the pattern of productive activity that is "costless" from the point of view of market transactions is attributed to change in total factor productivity. Thus the social accounting framework provides a definition of total factor productivity as the ratio of real product to real factor input.

To represent the system of social accounts that provides the basis for measuring total factor productivity, we introduce the following notation:

Y_i—quantity of the ith output,

X_j—quantity of the jth input,

q_i—price of the ith output,

p_j—price of the jth input.

Where there are m outputs and n inputs, the fundamental identity for each accounting period is that the value of output is equal to the value of input:

$$q_1Y_1+q_2Y_2+\ldots+q_mY_m=p_1X_1+p_2X_2+\ldots+p_nX_n. \qquad \ldots(1)$$

This accounting identity is important in defining an appropriate method for measuring total factor productivity; it also provides a useful check on the consistency of any proposed definitions of total output and total input.

To define total factor productivity we first differentiate (1) totally with respect to time and divide both sides by the corresponding total value. The result is an identity between a weighted average of the sum of rates of growth of output prices and quantities and a weighted average of the sum of rates of growth of input prices and quantities:

$$\Sigma w_i\left[\frac{\dot{q}_i}{q_i}+\frac{\dot{Y}_i}{Y_i}\right]=\Sigma v_j\left[\frac{\dot{p}_j}{p_j}+\frac{\dot{X}_j}{X_j}\right], \qquad \ldots(2)$$

with weights $\{w_i\}$ and $\{v_j\}$ given by the relative shares of the value of the ith output in the value of total output and the value of jth input in the value of total input:

$$w_i=\frac{q_iY_i}{\Sigma q_iY_i}, \quad v_j=\frac{p_jX_j}{\Sigma p_jX_j}.$$

To verify that both sides of (2) are weighted averages, we observe that:

$$w_i \geqq 0,\ i = 1 \ldots m;$$
$$v_j \geqq 0,\ j = 1 \ldots n;$$
$$\Sigma w_i = \Sigma v_j = 1.$$

A useful index of the quantity of total output may be defined in terms of the weighted average of the rates of growth of the individual outputs from (2); denoting this index of output by Y, the rate of growth of this index is

$$\frac{\dot{Y}}{Y} = \Sigma w_i \frac{\dot{Y}_i}{Y_i};$$

an analogous index of the quantity of total input, say X, has rate of growth

$$\frac{\dot{X}}{X} = \Sigma v_j \frac{\dot{X}_j}{X_j}.$$

These quantity indexes are familiar as Divisia quantity indexes; the corresponding Divisia price indexes for total output and total input, say q and p, have rates of growth:

$$\frac{\dot{q}}{q} = \Sigma w_i \frac{\dot{q}_i}{q_i},$$

$$\frac{\dot{p}}{p} = \Sigma v_j \frac{\dot{p}_j}{p_j},$$

respectively.[1]

In terms of Divisia index numbers a natural definition of total factor productivity, say P, is the ratio of the quantity of total output to the quantity of total input:

$$P = \frac{Y}{X}. \qquad \ldots(3)$$

Using the definitions of Divisia quantity indexes, Y and X, the rate of growth of total factor productivity may be expressed as:

$$\frac{\dot{P}}{P} = \frac{\dot{Y}}{Y} - \frac{\dot{X}}{X} = \Sigma w_i \frac{\dot{Y}_i}{Y_i} - \Sigma v_j \frac{\dot{X}_j}{X_j}. \qquad \ldots(4)$$

or, alternatively, as:

$$\frac{\dot{P}}{P} = \frac{\dot{p}}{p} - \frac{\dot{q}}{q} = \Sigma v_j \frac{\dot{p}_j}{p_j} - \Sigma w_i \frac{\dot{q}_i}{q_i}.$$

These two definitions of total factor productivity are dual to each other and are equivalent by (2). In general, any index of total factor productivity can be computed either from indexes of the quantity of total output and total input or from the corresponding price indexes.[2]

Up to this point we have defined total factor productivity as the ratio of certain index numbers of total output and total input. An economic interpretation of this definition may be obtained from the theory of production. The theory includes a production function

[1] Divisia [17, 19]. Application of these indexes to the measurement of total factor productivity is suggested by Divisia in a later publication [18, pp. 53-54]. The economic interpretation of Divisia indexes of total factor productivity has been discussed by Solow [61] and Richter [52].

[2] The basic duality relationship for indexes of total factor productivity has been discussed by Siegel, 57, 58].

characterized by constant returns to scale; writing this function in implicit form, we have:

$$F(Y_1, Y_2, \ldots, Y_m; X_1, X_2, \ldots, X_n) = 0.$$

Shifts in the production function may be defined in terms of appropriate weighted average rates of growth of outputs and inputs,

$$G\dot{P} = \sum\left(\frac{F_iY_i}{\Sigma F_iY_i}\cdot\frac{\dot{Y}_i}{Y_i}\right) - \sum\left(\frac{F_jX_j}{\Sigma F_jX_j}\cdot\frac{\dot{X}_j}{X_j}\right), \qquad \ldots(5)$$

where $F_i = \frac{\partial F}{\partial Y_i}$, $F_j = \frac{\partial F}{\partial X_j}$ and:

$$\frac{1}{G} = \Sigma F_iY_i = -\Sigma F_jX_j.$$

Changes in total factor productivity may be identified with shifts of the production function as opposed to movements along the production function by adding the necessary conditions for producer equilibrium—all marginal rates of transformation between pairs of inputs and outputs are equal to the corresponding price ratios—

$$\frac{\partial Y_i}{\partial X_j} = -\frac{F_j}{F_i} = \frac{p_j}{q_i}; \quad \frac{\partial Y_i}{\partial Y_k} = -\frac{F_k}{F_i} = \frac{q_i}{q_k}; \quad \frac{\partial X_j}{\partial X_l} = -\frac{F_l}{F_j} = \frac{p_l}{p_j}; \quad (i, k = 1\ldots m; \quad j, l = 1\ldots n).$$

Combining these conditions with the definition (5) of shifts in the production function, we obtain the definition (4) of total factor productivity:

$$G\dot{P} = \frac{\dot{P}}{P}.$$

The rate of growth of total factor productivity is zero if and only if the shift in the production function is zero.

The complete theory of production consists of a production function with constant returns to scale together with the necessary conditions for producer equilibrium. This theory of production implies the existence of a factor price frontier relating the prices of output to the prices of input. The dual to the definition (4) of total factor productivity may be identified with shifts in the factor price frontier.[1]

The economic interpretation of the index of total factor productivity is essential in measuring changes in total factor productivity by means of Divisia index numbers. As is well known,[2] the Divisia index of total factor productivity is a line integral so that its value normally depends on the path of integration; even if the path returns to its initial value the index of total factor productivity may increase or decrease. However, if price ratios are identified with marginal rates of transformation of a production function with constant returns to scale, the index will remain constant if the shift in the production function is zero.[3]

From either of the two definitions of the index of total factor productivity we have given it is obvious that the rate of growth of this index is not zero by definition. Even for a production function characterized by constant returns to scale with all factors paid the value of their marginal products, the rate of growth of real product may exceed or fall short of the rate of growth of real factor input; similarly, the rate of growth of the

[1] The notion of a factor price frontier has been discussed by Samuelson [54]; the factor price frontier is employed in defining changes in total factor productivity by Diamond [16] and by Phelps and Phelps [51].

[2] See, for example, Wold [64].

[3] See Richter [52]. We are indebted to W. M. Gorman for bringing this fact to our attention.

price of real factor input may exceed or fall short of the rate of growth of the price of real product.[1]

The economic theory of production on which our interpretation of changes in total factor productivity rests is not the only possible theory of production. From the definition of shifts in the production function (5) it is clear that the production function may be considered in isolation from the necessary conditions for producer equilibrium, provided that alternative operational definitions of the marginal rates of transformation are introduced. Such a production function may incorporate the effects of increasing returns to scale, externalities, and disequilibrium. Changes in total factor productivity in our sense could then be interpreted as movements along the production function in this more general sense.

To provide a basis for assessing the role of errors of measurement in explaining observed changes in total factor productivity, we first set out principles for measuring total output and total input. The measurement of flows of output and labour services is, at least conceptually, straightforward. Beginning with data on the value of transactions in each type of output and each type of labour service, this value is separated into a price and a quantity. A quantity index of total output is constructed from the quantities of each output, using the relative shares of the value of each output in the value of total output as weights. Similarly, a quantity index of total labour input is constructed from the quantities of each labour service, using the relative shares of the value of each labour service in the value of all labour services as weights.

If capital services were bought and sold by distinct economic units in the same way as labour services, there would be no conceptual or empirical difference between the construction of a quantity index of total capital input and the construction of the corresponding index of total labour input. Beginning with data on the value of transactions in each type of capital service, this value could be separated into a price of capital service or rental and a quantity of capital service in, say, machine hours. These data would correspond to the value of transactions in each type of labour service which could be separated into a price of labour service or wage and a quantity of labour service in, say, man hours. A quantity index of total capital input would be constructed from the quantities of each type of capital service, using the relative shares of the rental value of each capital service in the rental value of all capital services as weights.

The measurement of capital services is less straightforward than the measurement of labour services because the consumer of a capital service is usually also the supplier of the

[1] It is essential to distinguish our basic hypothesis from a misinterpretation of it recently advanced by Denison:

> Since advances in knowledge cannot increase national product without raising the marginal product of one or more factors of production, they of course disappear as a source of growth if an increase in a factor's marginal product resulting from the advance of knowledge is counted as an increase in the quantity of factor input [14, p. 76].

In terms of our social accounting framework Denison suggests that we measure factor input as the sum of the increase in both prices and quantities; denoting the index of input implied by Denison's interpretation by X^D, gives:

$$\frac{\dot{X}^D}{X^D} = \Sigma v_l \frac{\dot{p}_l}{p_l} + \Sigma v_l \frac{\dot{X}_l}{X_l};$$

the corresponding index of output, say Y^D, would then be defined as:

$$\frac{\dot{Y}^D}{Y^D} = \Sigma w_i \frac{\dot{q}_i}{q_i} + \Sigma w_i \frac{\dot{Y}_i}{Y_i};$$

The resulting index of total factor productivity, say P^D, is constant by definition:

$$\frac{\dot{P}^D}{P^D} = \frac{\dot{Y}^D}{Y^D} - \frac{\dot{X}^D}{X^D} = 0.$$

By comparing this definition with our definition (4), the error in Denison's interpretation of our hypothesis is easily seen.

service; the whole transaction is recorded only in the internal accounts of individual economic units. The obstacles to extracting this information for purposes of social accounting are almost insuperable; the information must be obtained by a relatively lengthy chain of indirect inference. The data with which the calculation begins are the values of transactions in new investment goods. These values must be separated into a price and quantity of investment goods. Second, the quantity of new investment goods reduced by the quantity of old investment goods replaced must be added to accumulated stocks. Third, the quantity of capital services corresponding to each stock must be calculated.[1]

Paralleling the calculation of quantities of capital services beginning with the quantities of new investment goods, the prices of capital services must be calculated beginning with the prices of new investment goods. Finally, a quantity index of total capital input must be constructed from the quantities of each type of capital service, using the relative shares of the implicit rental value of each capital service in the implicit rental value of all capital services as weights. The implicit rental value of each capital service is obtained by simply multiplying the quantity of that service by the corresponding price. At this final stage the construction of a quantity index of total capital input is formally identical to the construction of a quantity index of total labour input or total output. The chief difference between the construction of price and quantity indexes of total capital input and any other aggregation problem is in the circuitous route by which the necessary data are obtained.

The details of the calculation of a price and quantity of capital services from data on the values of transactions in new investment goods depend on empirical hypotheses about the rate of replacement of old investment goods and the quantity of capital services corresponding to a given stock of capital. In studies of total factor productivity it is conventional to assume that capital services are proportional to capital stock. Where independent data on rates of utilization of capital are available, this assumption can be dispensed with. A number of hypotheses about the rate of replacement of old investment goods have been used in the literature: (1) Accounting depreciation measured by the straight-line method is set equal to replacement, possibly with a correction for changes in prices. (2) Gross investment in some earlier period is set equal to replacement. (3) A weighted average of past investment with weights derived from studies of the "survival curves" of individual pieces of equipment[2] is set equal to replacement. From a formal point of view, the last of these hypotheses includes the first two as special cases.

We assume that the proportion of an investment replaced in a given interval of time declines exponentially over time. A theoretical justification for this assumption is that replacement of investment goods is a recurrent event. An initial investment generates a series of replacement investments over time; each replacement generates a new series of replacements, and so on; this process repeats itself indefinitely. The appropriate model for replacement of investment goods is not the distribution over time of replacements for a given investment, but rather the distribution over time of the infinite stream of replacements generated by a given investment. The distribution of replacements for such an infinite stream approaches a constant fraction of the accumulated stock of investment goods for any "survival curve" of individual pieces of equipment and for any initial age distribution of the accumulated stock, whether the stock is constant or growing. But this is precisely the relationship between replacement and accumulated stock if an exponentially declining proportion of any given investment is replaced in a given interval of time.

The quantity of capital services corresponding to each stock could be measured directly, at least in principle. The stock of equipment would be measured in numbers of

[1] Here we assume that the "quantity" of a particular type of capital as an asset is proportional to its "quantity" as a service, whatever the age of the capital. If this condition is not satisfied, capital of each distinct age must be treated as a distinct asset and service. Output at each point of time consists of the usual output plus "aged" capital stock.

[2] Studies in which these three methods have been employed are (1) Jaszi, Wasson, and Grose [33], Goldsmith [25], and Kuznets [39]; (2) Meyer and Kuh [44] and Denison [15]; (3) Terborgh [63].

machines while the service flow would be measured in machine hours, just as the stock of labour is measured in numbers of men while the flow of labour services is measured in man hours. While the stock of equipment may be calculated by cumulating the net flow of investment goods, the relative utilization of this equipment must be estimated in order to convert stocks into flows of equipment services. For the purposes of this study we assume that the relative utilization of all capital goods is the same; we estimate the relative utilization of capital from the relative utilization of power sources. An adjustment for the relative utilization of equipment is essential in order to preserve comparability among our measurements of output, labour input, and capital input.

To represent the capital accounts which provide the basis for measuring total capital input, we introduce the following notation:

I_k—quantity of output of the kth investment good,

K_k—quantity of input of the kth capital service.

As before, we use the notation:

q_k—price of the kth investment good,

p_k—price of the kth capital service.

Under the assumption that the proportion of an investment replaced in a given interval of time declines exponentially, the cumulated stock of past investments in the kth capital good, net of replacements, satisfies the well-known relationship:

$$I_k = \dot{K}_k + \delta_k K_k, \qquad \text{...(6)}$$

where δ_k is the instantaneous rate of replacement of the kth investment good. Similarly, in the absence of direct taxation the price of the kth capital service satisfies the relationship:

$$p_k = q_k\left[r + \delta_k - \frac{\dot{q}_k}{q_k}\right], \qquad \text{...(7)}$$

where r is the rate of return on all capital, δ_k is the rate of replacement of the kth investment good, and $\dot{q}_k/q_k$ is the rate of capital gain on that good. Given these relationships between the price and quantity of investment goods and the price and quantity of the corresponding capital services, the only data beyond values of transactions in new investment goods required for the construction of price and quantity indexes of total capital input are rates of replacement for each distinct investment good and the rate of return on all capital. We turn now to the problem of measuring the rate of return.

First, to measure the values of output and input it is customary to exclude the value of capital gains from the value of input rather than to include the value of such gains in the value of output. This convention has the virtue that the value of output may be calculated directly from the values of transactions. Second, to measure total factor productivity, depreciation is frequently excluded from both input and output; this convention is adopted, for example, by Kendrick [37]. Exclusion of depreciation on capital introduces an entirely arbitrary distinction between labour input and capital input, since the corresponding exclusion of depreciation of the stock of labour services is not carried out.[1] To calculate the rate of return on all capital, our procedure is to subtract from the value of output plus capital gains the value of labour input and of replacement. This results in the rate of return multiplied by the value of accumulated stocks. The rate of return is calculated by dividing this quantity by the value of the stock.[2] The

[1] This point is made by Domar [21].

[2] Domar's procedure [21, p. 717, fn. 3] fails to correct for capital gains. Implicitly, Domar is assuming either no capital gains or that all capital gains are included in the value of output, whether realized or not.

implicit rental value of the kth capital good is:

$$p_k K_k = q_k \left[r + \delta_k - \frac{\dot{q}_k}{q_k} \right] K_k.$$

To calculate price and quantity indexes for total capital input, the prices and quantities of each type of capital service are aggregated, using the relative shares of the implicit rental value of each capital service in the implicit rental value of all capital services as weights.

An almost universal conceptual error in the measurement of capital input is to confuse the aggregation of capital stock with the aggregation of capital service. This error may be exemplified by the following passage from a recent paper by Kendrick [38] devoted to theoretical aspects of capital measurement:

> . . . the prices of the underlying capital goods, as established in markets or imputed by owners, can be appropriately combined (with variable quantity weights) to provide a deflator to convert capital values into physical volumes of the various types of underlying capital goods at base-period prices. Or, the result can be achieved directly by weighting quantities by constant prices.
>
> As I view it, this is the most meaningful way to measure "real capital stock," since the weighted aggregate measures the physical complex of capital goods in terms of its estimated ability to contribute to production as of the base period.[1]

The "ability to contribute to production" is, of course, measured by the price of capital services, not the price of investment goods.[2]

We have already noted that direct observations are usually available only for values of transactions; the separation of these values into prices and quantities is based on much less complete information and usually involves indirect inferences; the presence of systematic errors in this separation is widely recognized. For output of consumption goods or input of labour services an error in separating the value of transactions into price and quantity results in an error in measurement of the price and quantity of total output or total labour input and in the measurement of total factor productivity. For example, suppose that the rate of growth of the price of a particular type of labour service is measured with an error; since all relative value shares remain the same, the resulting error in the price of total labour input has a rate of growth equal to the rate of growth of the error multiplied by the relative share of the labour service. The quantity of total labour input is measured with an error which is equal in magnitude but opposite in sign. The error in measurement of the rate of growth of total factor productivity is equal to the negative of the rate of growth of the error in the quantity of total labour input multiplied by the relative share of labour. The effects of an error in the rate of growth of the price of a particular type of consumption good are entirely analogous; of course, an upward bias in the rate of growth of output increases the measured rate of growth of total factor productivity, while an upward bias in the rate of growth of input decreases the measured rate of growth.

An error in the separation of the value of transactions in new investment goods into the price and quantity of investment goods will result in errors in measurement of the price and quantity of investment goods, of the price and quantity of capital services and of total

[1] Kendrick [38, p. 106]; see the comments by Griliches [27, p. 129]. Kendrick takes a similar position in a more recent paper [36]; see the comments by Jorgenson [35]. The treatment of capital input outlined above is based on our earlier paper [31]. The data have been revised to reflect recent revisions in the U.S. national accounts.

[2] The answer to Mrs. Robinson's [53] rhetorical question, "what units is capital measured in?" is dual to the measurement of the price of capital services. Given either an appropriate measure of the flow of capital services or a measure of its price, the other measure may be obtained from the value of income from capital. Since this procedure is valid only if the necessary conditions for producer equilibrium are satisfied, the resulting quantity of capital may not be employed to *test* the marginal productivity theory of distribution, as Mrs. Robinson and others have pointed out.

factor productivity. To measure the bias in the rate of growth of the quantity of investment goods, we let Q^* be the relative error in the measurement of the price of investment goods, I^* the "quantity" of investment goods output, calculated using the erroneous "price" of investment goods, and I the actual quantity of investment goods output. The bias in the rate of growth of investment goods output is then:

$$\frac{\dot I^*}{I^*} - \frac{\dot I}{I} = -\frac{\dot Q^*}{Q^*}; \qquad \text{...(8)}$$

The rate of growth of this bias is negative if the rate of growth of the error in measurement of the price of investment goods is positive, and vice-versa. If we let K^* be the "quantity" of capital calculated using the erroneous "price" of investment goods and K the actual quantity of capital:

$$K^* = \int_{-\infty}^{t} e^{-\delta(t-s)} I^*(s)ds = \int_{-\infty}^{t} e^{-\delta(t-s)} \frac{I(s)}{Q^*(s)} ds.$$

The bias in the rate of growth of the quantity of capital services is then:

$$\frac{\dot K^*}{K^*} - \frac{\dot K}{K} = \frac{I}{Q^*K^*} - \frac{I}{K} = \frac{I}{\int_{-\infty}^{t} e^{-\delta(t-s)} \frac{Q^*(t)}{Q^*(s)} I(s)ds} - \frac{I}{\int_{-\infty}^{t} e^{-\delta(t-s)} I(s)ds}, \qquad \text{...(9)}$$

which is negative if the rate of growth of the error in measurement of the price of investment goods is positive, and vice-versa.

To calculate the error of measurement in total factor productivity, we let C represent the quantity of consumption goods and L the quantity of labour input; second, we let w_I represent the relative share of the value of investment goods in the value of total output and w_C the relative share of consumption goods; finally, we let v_K represent the relative share of the value of capital input in the value of total input and v_L the relative share of labour. The rate of growth of total factor productivity may be represented as:

$$\frac{\dot P}{P} = w_I \frac{\dot I}{I} + w_C \frac{\dot C}{C} - v_K \frac{\dot K}{K} - v_L \frac{\dot L}{L}.$$

If we let P^* represent the measured index of total factor productivity using the erroneous "price" of investment goods:

$$\frac{\dot P^*}{P^*} = w_I \frac{\dot I^*}{I^*} + w_C \frac{\dot C}{C} - v_K \frac{\dot K^*}{K^*} - v_L \frac{\dot L}{L}.$$

Subtracting the first of these expressions from the second we obtain the bias in the rate of growth of total factor productivity:

$$\frac{\dot P^*}{P^*} - \frac{\dot P}{P} = w_I \left[\frac{\dot I^*}{I^*} - \frac{\dot I}{I}\right] - v_K \left[\frac{\dot K^*}{K^*} - \frac{\dot K}{K}\right].$$

Substituting expressions (9) and (8) for the biases in the measured rates of growth of capital input and the output of investment goods, we have:

$$\frac{\dot P^*}{P^*} - \frac{\dot P}{P} = -w_I \frac{\dot Q^*}{Q^*} - v_K \left(\frac{I}{\int_{-\infty}^{t} e^{-\delta(t-s)} \frac{Q^*(t)}{Q^*(s)} I(s)ds} - \frac{I}{\int_{-\infty}^{t} e^{-\delta(t-s)} I(s)ds} \right). \qquad \text{...(10)}$$

If investment and the error in measurement are growing at constant rates, the biases in the rates of growth of the quantity of investment goods produced and the quantity of capital services are equal, so that the net effect is equal to the rate of growth in the error in measurement of the price of investment goods multiplied by the difference between the capital share in total input and the investment share in total output.[1]

A second source of errors in measurement arises from limitations on the number of separate inputs that may be distinguished empirically. The choice of commodity groups to serve as distinct " inputs " and " outputs " involves aggregation within each group by simply adding together the quantities of all commodities within the group and aggregation among groups by computation of the usual Divisia quantity index. The resulting price and quantity indexes are Divisia price and quantity indexes of the individual commodities only if the rates of growth either of prices or of quantities within each group are identical.

Errors of aggregation in studies of total factor productivity have not gone unnoticed; however, these errors are frequently mislabelled as "quality change". Quality change in this sense occurs whenever the rates of growth of quantities within each separate group are not identical. For example, if high quality items grow faster than items of low quality, the rate of growth of the group is biased downward relative to an index treating high and low quality items as separate commodities. To eliminate this bias it is necessary to construct the index of input or output for the group as a Divisia index of the individual items within the group. Elimination of " quality change " in the sense of aggregation bias is essential to accurate social accounting and to measurement of changes in total factor productivity. Separate accounts should be maintained for as many product and factor input categories as possible. An attempt should be made to exploit available detail in any empirical measurement of real product, real factor input, and total factor productivity.

In some contexts the choice of an appropriate unit for the measurement of quantities of real product or real factor input is not obvious. For example, fuel may be measured in tons or in B.T.U. equivalents, tractor services may be measured in tractor hours or in horsepower hours, and so on. Measures of real product and real factor input may be adjusted for " quality change " by converting one unit of measurement to another. This procedure conforms to the principles of social accounting we have outlined and their interpretation in terms of the economic theory of production if the adjustment for quality change corrects errors of aggregation. In the examples we have given, if the marginal products of different types of fuel always move in proportion when fuel is measured in B.T.U. equivalents but fail to do so when fuel is measured in tons, the appropriate unit for the measurement of fuel is the B.T.U. Similarly, if the marginal products of tractor services measured in horsepower hours always move in proportion, but when measured in tractor hours fail to do so, tractor services should be measured in horsepower hours.

The appropriateness of any proposed adjustment for quality change may be confronted with empirical evidence on the marginal products of individual items within a commodity group. Under the assumption that these products are equal to the corresponding price ratios this evidence takes the form of data on relative price movements for the individual items. Under a more general set of assumptions the marginal products might be calculated from an econometric production function. The latter treatment would be especially useful for " linking in " new factors and products since the relevant prices cannot be observed until the new factors and products appear in the market. Any change in measured total factor productivity resulting from adjustments for quality change is explained by evidence on the movement of marginal products and is not the result of an arbitrary choice of definitions. The choice of appropriate units for measurement of

[1] Domar [22, p. 587, formula (5)] considers a special case of this problem in which capital " is imported from the outside". This specialization is unnecessary, as suggested in the text. A more detailed discussion of this issue is presented by Jorgenson [35].

For constant rates of growth of the relative error in the investment goods price index and the level of investment, formula (10) may be expressed in closed form:

$$\frac{\dot{P}^*}{P^*} - \frac{\dot{P}}{P} = -w_I \frac{\dot{Q}^*}{Q^*} + v_K \frac{\dot{Q}^*}{Q^*},$$
$$= (v_K - w_I) \frac{\dot{Q}^*}{Q^*}.$$

real product and real factor input may go beyond selection among alternative scalar measured such as B.T.U. equivalents or tons; a commodity may be regarded as multi-dimensional and an appropriate unit of measurement may be defined implicitly by taking prices as given by so-called "hedonic" price indexes. The critical property of such price indexes is that when prices are given by a "hedonic" price index for the commodities within a group, all such commodities have marginal rates of transformation *vis-à-vis* commodities outside the group that move in proportion to each other. Insofar as this property is substantiated by empirical evidence, adjustment of the commodity group for "quality change" by means of such a price index is entirely legitimate and amounts to correcting an error of aggregation.[1] This is not to say that any proposed adjustment for quality change is legitimate. The appropriateness of each adjustment must be judged on the basis of the evidence. If no fresh evidence is employed, the choice of appropriate units is entirely arbitrary and any change in measured total factor productivity resulting from adjustment for "quality change" is simply definitional.

"Quality change" is sometimes used to describe a special type of aggregation error, namely, the error that arises in aggregating investment goods of different vintages by simply adding together quantities of investment goods of each vintage. If the quality of investment goods, as measured by the marginal productivity of capital, is not constant over all vintages, this procedure results in aggregation errors. An appropriate index of capital services may be constructed by treating each vintage of investment goods as a separate commodity. To construct such an index empirically, data on the marginal productivity of capital of each vintage at each point of time are required. If independent data on relative prices of capital services of different vintages are used in the construction of such a capital services index, any resulting reduction in measured productivity growth is not tautological. Only where the change in quality is measured indirectly from the resulting increase in total factor productivity, as suggested by Solow [60], does such a procedure result in the elimination of productivity change by definition.[2]

3. MEASUREMENT

3.1. *Initial estimates*

We can now investigate the extent to which measured changes in total factor productivity are due to errors of measurement. We begin by constructing indexes of total output and total input for the United States for the twenty-year period following World War II, 1945-65, without correcting for errors of measurement. As an initial index of total output we take U.S. private domestic product in constant prices as measured in the U.S. national product accounts [48]. As an index of total input we take the sum of labour and capital services in constant prices. Labour and capital services are assumed to be proportional to stocks of labour and capital, respectively. The stock of labour is taken to be the number of persons engaged in the private domestic sector of the U.S. economy. The stock of capital is the sum of land, plant, equipment, and inventories employed in this sector.[3] The rate of growth of total factor productivity is equal to the difference in the rates of growth of total output and total input.

Indexes of total output, total input, and total factor productivity are given in Table I. The average annual rate of growth of total output over the period 1945-65 is 3·49 per cent. The average rate of growth of total input is 1·83 per cent. The average rate of growth of total factor productivity is 1·60 per cent. The rate of growth of total input explains 52·4

[1] See Griliches [28] and the references given there.

[2] Jorgenson [35].

[3] To make stocks of labour and capital precisely analogous, it would be necessary to go even further. Unemployed workers should be included in the stock of labour since unemployed machines are included in the stock of capital. Workers should be aggregated by means of discounted lifetime incomes since capital goods are aggregated by means of asset prices.

TABLE I

Total output, input, and factor productivity, U.S. private domestic economy, 1945-65, initial estimates

	1	2	3
1945	0·699	0·786	0·891
1946	0·680	0·817	0·836
1947	0·695	0·854	0·818
1948	0·729	0·876	0·836
1949	0·726	0·867	0·841
1950	0·801	0·891	0·901
1951	0·852	0·928	0·919
1952	0·873	0·947	0·924
1953	0·917	0·966	0·951
1954	0·904	0·954	0·949
1955	0·981	0·976	1·005
1956	0·999	1·001	0·998
1957	1·013	1·012	1·000
1958	1·000	1·000	1·000
1959	1·069	1·019	1·048
1960	1·096	1·036	1·057
1961	1·115	1·039	1·072
1962	1·189	1·057	1·123
1963	1·240	1·074	1·152
1964	1·307	1·097	1·188
1965	1·387	1·129	1·224

1. Output. 2. Input. 3. Productivity.

per cent of the growth in output; the remainder is explained by changes in total factor productivity.

3.2. *Errors of aggregation*

The first error of measurement to be eliminated is an error of aggregation. This error results from aggregating labour and capital services by summing quantities in constant prices. To eliminate the error, we replace our initial index of total input by a Divisia index of labour and capital input, as suggested by Solow [61]. A similar error results from aggregating consumption and investment goods output by adding together quantities in constant prices. This error may be eliminated by replacing our initial index of total output by a Divisia index of consumption and investment goods output. Indexes of total output, total input, and total factor productivity with these errors of aggregation eliminated are presented in Table II.

The average annual rate of growth of total output over the period 1945-65 with the error in aggregation of consumption and investment goods output eliminated is 3·39 per cent. The average rate of growth of total input with the error in aggregation of labour and capital services eliminated is 1·84 per cent. The resulting rate of growth of total factor productivity is 1·49 per cent. We conclude that these errors in aggregation result in an overstatement of the initial rate of growth of total factor productivity. With these errors eliminated total input explains 54·3 per cent of the growth in total output. This result may be compared with the 52·4 per cent of the growth in total output explained initially.

3.3. *Investment goods prices*

We have demonstrated that an error in the measurement of investment goods prices results in errors in the measurement of total output, total input, and total factor productivity.

Roughly speaking, a positive bias in the rate of growth of the investment goods price index results in a positive bias in the rate of growth of total factor productivity, provided that the share of capital in the value of input exceeds the share of investment in the value of output. This condition is fulfilled for the U.S. private domestic sector throughout the period, 1945-65. Hence, we must examine the indexes of investment goods prices that underlie our measurement for possible sources of bias.

Except for the price index for road construction the price indexes for structures that underlie the U.S. national accounts are indexes of the cost of input rather than the price of output. In the absence of changes in total factor productivity properly constructed

TABLE II

Total output, input, and factor productivity, U.S. private domestic economy, 1945-65, errors of aggregation eliminated

	1	2	3
1945	0·713	0·783	0·912
1946	0·679	0·810	0·841
1947	0·694	0·847	0·824
1948	0·727	0·870	0·840
1949	0·727	0·864	0·845
1950	0·800	0·888	0·903
1951	0·851	0·925	0·921
1952	0·873	0·945	0·926
1953	0·918	0·964	0·953
1954	0·905	0·954	0·950
1955	0·981	0·976	1·005
1956	0·999	1·001	0·998
1957	1·013	1·012	1·000
1958	1·000	1·000	1·000
1959	1·070	1·019	1·049
1960	1·096	1·036	1·057
1961	1·115	1·038	1·073
1962	1·189	1·057	1·124
1963	1·240	1·073	1·153
1964	1·307	1·096	1·189
1965	1·387	1·128	1·225

1. Output. 2. Input. 3. Productivity.

price indexes for construction input would parallel the movements of price indexes for output. This is assured by the dual to the usual definition of total factor productivity (3). Dacy [12] has shown that the rate of growth of the price of inputs in highway construction is considerably greater than that of the price of construction output. Dacy's output price index grows from 0·805 to 0·982 from 1947 through 1959, while the input price index grows from 0·615 to 1·024 in the same period, both on a base 1·000 in 1958.[1] This empirical finding is simply another way of looking at the positive residual between rates of growth of total output and total input where total factor productivity is measured with error. Input price indexes are subject to the same errors of aggregation as the corresponding quantity indexes. Since input quantity indexes grow too slowly, input price indexes grow too rapidly.

[1] The growth of the output price index may be compared with that for personal consumption expenditures, which grows from 76·5 to 108·6 from 1947 through 1959. The close parallel between the output price index for construction and the price of consumption goods suggests an explanation for the difference in rates of growth of prices of consumption and investment goods described by Gordon [26]. This difference results from the error of measurement in using an input price index in place of an output price index for investment goods. If this error is corrected, the difference vanishes.

The use of input prices in place of output prices for structures results in an important error of measurement. To eliminate this error it is necessary to use an output price index in measuring prices of both investment goods output and capital services input. An index of this type has been constructed for the OBE 1966 Capital Stock Study [49]. Components of this index include the Bureau of Public Roads price index for highway structures, the Bell System price index for telephone buildings, and the Bureau of Reclamation price indexes for pumping plants and power plants. The resulting composite index may be compared with the implicit deflator for new construction from the U.S. national accounts [48]. The implicit deflator grows from 0·686 to 1·029 during the period 1947 through 1959 while the OBE Capital Goods Study price index for new construction output grows

TABLE III

Alternative investment deflators

	1	2	3	4	5	6
1945	0·544	0·510	0·759	0·517	0·633	0·357
1946	0·594	0·570	0·768	0·575	0·705	0·638
1947	0·721	0·686	0·827	0·646	0·786	2·310
1948	0·749	0·770	0·863	0·703	0·827	1·023
1949	0·743	0·755	0·868	0·736	0·818	0·786
1950	0·763	0·791	0·878	0·752	0·823	0·818
1951	0·836	0·847	0·942	0·809	0·879	0·945
1952	0·881	0·876	0·954	0·822	0·896	0·949
1953	0·895	0·889	0·943	0·835	0·903	0·497
1954	0·897	0·886	0·929	0·840	0·914	0·772
1955	0·902	0·910	0·919	0·859	0·921	0·931
1956	0·959	0·956	0·949	0·918	0·945	0·978
1957	1·001	0·992	0·984	0·975	0·978	1·113
1958	1·000	1·000	1·000	1·000	1·000	0·994
1959	1·006	1·029	1·014	1·020	1·012	0·991
1960	1·005	1·042	1·009	1·022	1·026	1·020
1961	1·008	1·053	1·006	1·021	1·037	1·011
1962	1·024	1·069	1·008	1·023	1·048	1·001
1963	1·038	1·089	1·004	1·023	1·059	1·011
1964	1·059	1·119	1·004	1·031	1·071	1·014
1965	1·089	1·149	0·995	1·038	1·089	1·032

1. Structures II.
2. Structures I.
3. Equipment II.
4. Equipment I.
5. Inventories II.
6. Inventories I.

from 0·762 to 0·958 during the same period. Thus the relative bias in the input price index for all new construction as a measure of the price of construction output is roughly comparable to the relative bias in Dacy's input price index for highway construction as a measure of the price of highway construction output. The input price index, labelled Structures I, and the output price index, labelled Structures II, are given in Table III.

The price indexes for equipment that underlie the U.S. national accounts are based primarily on data from the wholesale price index of the Bureau of Labour Statistics [6]. Since expenditures on the wholesale price index are less than those on the consumers' price index [4], adjustments for quality change are less frequent and less detailed. A direct comparison of the durables components of the wholesale and consumers' price indexes gives some notion of the relative bias. The wholesale price index increases from 0·646 to 1·023 and the consumers' price index increases from 0·858 to 1·022 over the period 1947 to 1959, both on a base of 1·000 in 1958. A direct comparison of components common to both indexes reveals essentially the same relationship. To correct for bias

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in the implicit deflator for producers' durables, we substitute for this deflator the implicit deflator for consumers' durables. The deflator for producers' durables increased from 0·646 in 1947 to 1·020 in 1959. Over this same period the deflator for consumers' durables increased from 0·827 to 1·014, both on a base of 1·000 in 1958. Thus the relative bias in the producers' durables price index as revealed by a comparison with components common to the wholesale and consumers' price indexes may be corrected by simply substituting the implicit deflator for consumers' durables for the producers' durables deflator. Both indexes are given in Table III; the producers' durables index is labelled Equipment I while the consumers' durables index is labelled Equipment II.

The durables component of the consumers' price index was itself subject to considerable upward bias in recent years. The consumers' price index for new automobiles increased 62 per cent from 1947 to 1959. It has been estimated that correcting this index for quality change would reduce this increase to only 31 per cent in the same period.[1] In view of the upward bias in the consumers' price index our adjustment for bias in the producers' durables price index is conservative. In order to reduce the error of measurement further, detailed research like that already carried out for automobiles is required for each class of producers' durable equipment.

The price indexes for change in business inventories from the U.S. national accounts contain year-to-year fluctuations that result from changes in the composition of investment in inventories; these changes are much more substantial than the corresponding changes in the composition of inventory stocks. The implicit deflator for change in inventories is not published; however, it may be computed from data on change in inventories in current and constant dollars. Changes that amount to nearly doubling or halving the index occur from 1946 to 1947, 1947 to 1948, and 1951 to 1952. The value of the index is 0·357 in 1945, 0·638 in 1946 and 2·310 in 1947, all on a base of 1·000 (or, to be exact, 0·994) in 1958. The index drops to 1·023 in 1948 and 0·788 in 1949. A less extreme but equally substantial movement in the index occurs from 1952 through 1957. Changes in the implicit deflator of this magnitude cannot represent movements in the price of all stocks of inventories considered as investment goods. To represent these movements more accurately, we replace the implicit deflator for change in inventories by the deflator for private domestic consumption expenditures. The level of this index generally coincides with that of the implicit deflator for change in business inventories; however, the fluctuations are much less. Both indexes are given in Table III; the implicit deflator for change in business inventories is labelled Inventories I while the implicit deflator for private domestic consumption expenditures is labelled Inventories II.

Indexes of total input, total output, and total factor productivity with errors in the measurement of prices of investment goods eliminated are presented in Table IV. The average rate of growth of total output over the period 1945-65 with these errors of measurement removed is 3·59 per cent. This rate of growth may be compared with the original rate of growth of total output of 3·49 per cent or with the rate of growth of 3·39 per cent for total output with errors of aggregation removed. The average rate of growth of total input over this period is 2·19 per cent. The original rate of growth of total input is 1·83 per cent; with errors of aggregation removed the rate of growth of total input is 1·84 per cent. The rate of growth of total factor productivity is 1·41 per cent. With errors in measurement of the prices of investment goods eliminated the rate of growth of total input explains 61·0 per cent of the rate of growth of total output.

3.4. *Measurement of services*

Up to this point we have assumed that labour and capital services are proportional to stocks of labour and capital. This assumption is obviously incorrect. In principle flows of capital and labour services could be measured directly. In fact it is necessary to

[1] Griliches [28, Table 8, last column, p. 397].

infer the relative utilization of stocks of capital and labour from somewhat fragmentary data. Okun [50] has attempted to circumvent the problem of direct observation of labour and capital services by assuming that the relative utilization of both labour and capital is a function of the unemployment rate for labour so that the gap between actual and "potential" output, that is, output at full utilization of both factors, may be expressed in terms of the unemployment rate. A similar notion has been used by Solow [62] to adjust stocks of labour and capital for relative utilization. Most of the available capacity utilization measures are based on the relationship of actual output to output at full utilization of both labour and capital, so that these measures also attempt to adjust both labour and capital simultaneously.

TABLE IV

Total output, input, and factor productivity, U.S. private domestic economy, 1945-65, errors in investment goods prices eliminated

	1	2	3
1945	0·692	0·759	0·913
1946	0·662	0·786	0·846
1947	0·679	0·822	0·829
1948	0·718	0·845	0·853
1949	0·717	0·842	0·854
1950	0·798	0·867	0·922
1951	0·839	0·908	0·925
1952	0·858	0·930	0·925
1953	0·905	0·950	0·954
1954	0·900	0·942	0·957
1955	0·982	0·966	1·016
1956	0·995	0·996	0·999
1957	1·009	1·010	1·000
1958	1·000	1·000	1·000
1959	1·076	1·022	1·052
1960	1·107	1·042	1·061
1961	1·127	1·049	1·073
1962	1·199	1·071	1·117
1963	1·249	1·091	1·142
1964	1·319	1·117	1·177
1965	1·400	1·153	1·209

1. Output. 2. Input. 3. Productivity.

Our approach to the problem of relative utilization is somewhat more direct in that we attempt to adjust capital and labour for relative utilization separately. Of course, this adjustment gives rise to a new concept of "potential" or capacity output, but we do not pursue this notion further in this paper. Our first assumption is that the relative utilization of capital is the same for all capital goods; while this is a very strong assumption it is weaker than the assumption underlying the Okun-Solow approach in which the relative utilization of capital and labour depends on that of labour. We estimate the relative utilization of capital from the relative utilization of power sources.[1] Data on the relative utilization of electric motors provides an indicator of the relative utilization of capital in manufacturing, since electric motors are the predominant source of power there. We assume that relative utilization of capital goods in the manufacturing and non-manufacturing sectors is the same. When more complete data become available, this assumption can be replaced by less restrictive assumptions. Unfortunately, this adjustment

[1] Foss [24]. See the Statistical Appendix for further details.

allows only for the trend in the relative utilization of capital; it does not adjust for short-term cyclical variations in capacity utilization. Thus we are unable to attain the objective of complete comparability between measures of labour and capital input.

The assumption that labour services are proportional to the stock of labour is obviously incorrect. On the other hand, the assumption that labour services can be measured directly from data on man-hours is equally incorrect, as Denison [14] has pointed out. The intensity of effort varies with the number of hours worked per week, so that labour input can be measured accurately only if data on man-hours are corrected for the effects of variations in the number of hours per man on labour intensity. Denison [15] suggests that the stock of labour provides an upper bound for labour services while the number of man-hours provides a lower bound. He estimates labour input by correcting man-hours for variations in labour intensity. We employ Denison's correction for intensity,

TABLE V

Total input and factor productivity, U.S. private domestic economy, 1945-65, errors in relative utilization eliminated

	1	2
1945	0·716	0·968
1946	0·742	0·895
1947	0·777	0·877
1948	0·801	0·899
1949	0·802	0·897
1950	0·830	0·963
1951	0·873	0·963
1952	0·899	0·956
1953	0·924	0·980
1954	0·923	0·976
1955	0·959	1·023
1956	0·994	1·001
1957	1·009	1·000
1958	1·000	1·000
1959	1·035	1·038
1960	1·057	1·046
1961	1·067	1·054
1962	1·089	1·098
1963	1·114	1·118
1964	1·146	1·147
1965	1·189	1·172

1. Input. 2. Productivity.

but we apply this correction to actual hours per man rather than potential hours per man. Thus, our measure of labour input reflects short-run variations in labour intensity.

The assumption that labour and capital services are proportional to stocks of labour and capital results in an error in separating a given value of transactions into a price and a quantity. To correct this error we multiply the number of persons engaged by hours per man. The resulting index of man-hours is then corrected for variations in labour intensity. The corresponding error for capital is corrected by multiplying the stock of capital by the relative utilization of capital. Indexes of total input and total factor productivity after these errors have been eliminated are presented for the period 1945-65 in Table V. The average annual rate of growth of total output is the same as before these corrections, 3·59 per cent per year. The average rate of growth of total input is 2·57 per cent. The resulting average rate of growth of total factor productivity is 0·96 per cent. Total input now explains 71·6 per cent of the rate of growth in total output.

3.5. *Capital services*

In converting estimates of capital stock into estimates of capital services we have disregarded an important conceptual error in the aggregation of capital services. While investment goods output must be aggregated by means of investment goods or asset prices, capital services must be aggregated by means of service prices.

The prices of capital services are related to the prices of the corresponding investment goods; in fact, the asset price is simply the discounted value of all future capital services. Asset prices for different investment goods are not proportional to service prices because of differences in rates of replacement and rates of capital gain or loss among capital goods. Implicitly, we have assumed that these prices are proportional; to eliminate the resulting error in measurement, it is necessary to compute service prices and to use these prices in aggregating capital services.

We have already outlined a method for computing the price of capital services in the absence of direct taxation of business income. In the presence of direct taxes we may distinguish between the price of capital services before and after taxes. The expression (7) given above for the price of capital services is the price after taxes. The price of capital services before taxes is:

$$p_k = q_k\left[\frac{1-uv}{1-u}\,r+\frac{1-uw}{1-u}\,\delta_k-\frac{1-ux}{1-u}\,\frac{\dot{q}_k}{q_k}\right] \qquad \ldots(11)$$

where u is the rate of direct taxation, v the proportion of return to capital allowable as a charge against income for tax purposes, w the proportion of replacement allowable for tax purposes, and x the proportion of capital gains included in income for tax purposes

We estimate the variables describing the tax structure as follows: The rate of direct taxation is the ratio of profits tax liability to profits before taxes. The proportion of the return to capital allowable for tax purposes is the ratio of net interest to the total return to capital. Total return to capital is the after tax rate of return, r, multiplied by the current value of capital stock. The proportion of replacement allowable for tax purposes is the ratio of capital consumption allowances to the current value of replacement. The proportion of capital gains included in income is zero by the conventions of the U.S. national accounts. Given the value of direct taxes we estimate the after tax rate of return by subtracting from the value of output plus capital gains the value of labour input, replacement, and direct taxes. This results in the total return to capital. The rate of return is calculated by dividing this quantity by the current value of the stock of capital. Given data on the rate of return and the variables describing the tax structure, we calculate the price of capital services before taxes for each investment good.[1] These prices of capital services are used in the calculation of indexes of capital input, total input, and total factor productivity.

For the U.S. private domestic economy it is possible to distinguish five classes of investment goods—land, residential and non-residential structures, equipment, and inventories. Although it is also possible to distinguish a number of sub-classes within each of these groupings, we will employ only the five major groups in calculating an index of total capital input. For each group we first compute a before tax service price analogous to (11). We then compute an index of capital input as a Divisia index of the services of land, structures, equipment and inventories. In constructing this index we eliminate the conceptual error that arises from the implicit assumption that service prices are proportional to asset prices for different investment goods. In eliminating this conceptual error we also eliminate the error of aggregation that results from adding together capital services in constant prices to obtain an index of total capital input. To eliminate the corresponding error in our index of investment goods output we replace our initial index by a Divisia index of investment in structures, equipment, and inventories. Indexes of total output, total input and total factor productivity resulting from the elimination of these errors are

[1] Further details are given in the Statistical Appendix.

presented in Table VI. The after tax rate of return implicit in the new index of capital input is also given in Table VI.

The average rate of growth of total output over the period 1945-65 with the error in aggregation of investment goods eliminated is 3·59. This rate of growth is essentially the same as for total output with errors in the aggregation of consumption and investment goods and errors in the measurement of investment goods prices eliminated. The average rate of growth of total input with errors in aggregation of capital services eliminated is 2·97 per cent. This rate of growth may be compared with the initial rate of growth of 1·83 per cent.

TABLE VI

Total input and factor productivity, U.S. private domestic economy, 1945-65, errors in aggregation of capital input eliminated; implicit rate of return after taxes

	1	2	3	4
1945	0·692	0·671	1·030	0·158
1946	0·661	0·698	0·950	0·198
1947	0·678	0·735	0·926	0·237
1948	0·717	0·765	0·940	0·223
1949	0·716	0·773	0·930	0·126
1950	0·797	0·804	0·992	0·095
1951	0·837	0·850	0·986	0·242
1952	0·857	0·880	0·976	0·143
1953	0·905	0·908	0·997	0·091
1954	0·900	0·911	0·988	0·078
1955	0·982	0·951	1·032	0·113
1956	0·995	0·987	1·008	0·175
1957	1·009	1·005	1·004	0·138
1958	1·000	1·000	1·000	0·107
1959	1·077	1·039	1·035	0·097
1960	1·107	1·063	1·040	0·105
1961	1·127	1·076	1·046	0·118
1962	1·199	1·099	1·089	0·138
1963	1·250	1·126	1·107	0·131
1964	1·320	1·160	1·134	0·127
1965	1·401	1·206	1·157	0·141

1. Output. 2. Input. 3. Productivity. 4. Rate of return.

The resulting rate of growth of total factor productivity is 0·58 per cent. The index of total factor productivity with these errors eliminated is presented in Table VI. With these errors eliminated total input explains 82·7 per cent of the growth in total output. The original index of total input explains 52·4 per cent of this growth.

3.6. *Labour services*

We have eliminated errors of aggregation that arise in combining capital services into an index of total capital input. Similar errors arise in combining different categories of labour services into an index of total labour input. Implicitly, we have assumed that the price per man-hour for each category of labour services is the same; to eliminate the resulting error of measurement it is necessary to use prices per man-hour for each category in computing an index of total labour input. Second, to eliminate the error of aggregation that results from adding together labour services in constant prices, we replace our initial index of labour input by a Divisia index of the individual categories of labour services.

The Divisia index of total labour input is based on a weighted average of the rates of growth of different categories of labour, using the relative shares in total labour compensation as weights. To represent our index of total labour input, we let L_l represent the quantity of input of the lth labour service, measured in man-hours. The rate of growth of the index of total labour input, say L, is:

$$\frac{\dot{L}}{L} = \Sigma v_l \frac{\dot{L}_l}{L_l}$$

where v_l is the relative share of the lth category of labour in the total value of labour input. The number of man-hours for each labour service is the product of the number of men, say n_l, and hours per man, say h_l; using this notation the index of total labour input may be rewritten:

$$\frac{\dot{L}}{L} = \Sigma v_l \frac{\dot{n}_l}{n_l} + \Sigma v_l \frac{\dot{h}_l}{h_l}.$$

For comparison with our initial indexes of labour input we separate the rate of growth of the index of labour input into three components—change in the total number of men, change in hours per man, and change in labour input per man-hour. We have assumed that the number of hours per man is the same for all categories of labour services, say H. Letting N represent the total number of men and e_l the proportion of the workers in the lth category of labour serivces, we may write the index of total labour input in the form:

$$\frac{\dot{L}}{L} = \frac{\dot{H}}{H} + \frac{\dot{N}}{N} + \Sigma v_l \frac{\dot{e}_l}{e_l} \qquad \text{...(12)}$$

Our initial index of labour input was simply N, the number of persons engaged; we corrected this index by taking into account the number of hours per man, H. To eliminate the remaining errors of aggregation we must correct the rate of growth of man-hours by adding to it an index of labour input per man-hour. The third term in the expression (12) for total labour input given above provides such an index. We will let E represent this index, so that:

$$\frac{\dot{E}}{E} = \Sigma v_l \frac{\dot{e}_l}{e_l}. \qquad \text{...(13)}$$

For computational purposes it is convenient to note that the index may be rewitten in the form:

$$\frac{\dot{E}}{E} = \Sigma \frac{p_l}{\Sigma p_l e_l} \dot{e}_l = \Sigma p_l' \dot{e}_l,$$

where p_l is the price of the lth category of labour services and p_l' is the relative price. The relative price is the ratio of the price of the lth category of labour services to the average price of labour services, $\Sigma p_l e_l$.

In principle it would be desirable to distinguish among categories of labour services classified by age, sex, occupation, number of years schooling completed, industry of employment, and so on. An index of labour input per man-hour based on such a breakdown requires detailed research far beyond the scope of this study. We will compute such an index only for males and only for categories of labour broken down by the number of school years completed. The basic computation is presented in Table VII. Data on relative prices for labour services are available for the years 1939, 1949, 1956, 1958, 1959 and 1963.[1] Combining these prices with changes in the distribution of the labour force provides a measure of the change in labour input per man-hour.[2]

[1] Additional details on relative prices for labour services are presented in the Statistical Appendix, Table XII.

[2] Additional details on the distribution of the labour force are presented in the Statistical Appendix, Table XI.

TABLE VII

Relative prices, changes in distribution of the labour force, and indexes of labour-input per man-hour, U.S. males, the civilian labour force, 1940-64*

School year completed	p_i'	Δe_i	p_i'	Δe_i	p_i'	Δe_i	p_i'	Δe_i	p_i'	Δe_i	p_i'	Δe_i
	1939	1940-48	1949	1948-52	1956	1952-57	1958	1957-59	1959	1959-62	1963	1962-65
Elementary 0-4	0·497	−2·3	0·521	−0·3	0·452	−1·3	0·409	−0·8	0·498	−0·8	0·407	−0·8
5-6 or 5-7	0·672	−3·1	0·685	−0·5	0·624	−0·2	0·565	−1·0	0·688	−0·9	0·562	−1·5
7-8 or 8	0·887	−6·8	0·813	−1·8	0·796	−3·3	0·753	−1·2	0·801	−1·9	0·731	−1·2
High School 1-3	1·030	2·4	0·974	−1·3	0·955	0·7	0·923	0·6	0·912	−0·6	0·886	−0·3
4	1·241	7·0	1·143	1·0	1·159	2·6	1·113	0·9	1·039	1·6	1·087	3·2
College 1-3	1·442	1·4	1·336	1·2	1·356	0·2	1·392	0·7	1·255	1·3	1·269	0·0
4+ or 4	1·947	1·3	1·866	1·6	1·810	1·3	1·840	0·9	1·569	1·0	1·571	0·2
5+	...	...	...	...	...	...	...	...	1·888	0·3	1·730	0·4
Percentage change in labour input per man-hour		6·45		2·50		2·97		2·39		2·36		2·13
Annual percentage change		0·78		0·62		0·59		1·20		0·79		0·72

SOURCE: Derived from Tables 11 and 12, Statistical Appendix.

* The relative prices are computed using the appropriate beginning period distribution of the labour force as weights.

Indexes of total input and total factor productivity with errors in the aggregation of labour services eliminated are presented in Table VIII. The average rate of growth of total input over the period 1945-65 with the error in aggregation of labour services eliminated is 3·47. This rate of growth may be compared with the initial rate of growth of total input of 1·83 per cent. The resulting rate of growth of total factor productivity is 0·10 per cent. With these errors eliminated total input explains 96·7 per cent of the growth in total output.

TABLE VIII

Total input and factor productivity, U.S. private domestic economy 1945-65, errors in aggregation of labour input eliminated

	1	2
1945	0·634	1·090
1946	0·661	1·001
1947	0·700	0·971
1948	0·732	0·981
1949	0·743	0·966
1950	0·776	1·026
1951	0·823	1·017
1952	0·857	1·002
1953	0·887	1·020
1954	0·894	1·007
1955	0·936	1·048
1956	0·976	1·019
1957	0·997	1·012
1958	1·000	1·000
1959	1·047	1·027
1960	1·077	1·027
1961	1·096	1·027
1962	1·125	1·064
1963	1·158	1·076
1964	1·200	1·096
1965	1·255	1·112

1. Input. 2. Productivity.

4. SUMMARY AND CONCLUSION

4.1. *Summary*

The purpose of this paper has been to examine the hypothesis that if quantities of output and input are measured accurately, growth in total output may be largely explained by growth in total input. The results are given in Table IX and Charts 1, 2 and 3. We first present our initial estimates of rates of growth of output, input, and total factor productivity. These estimates include many of the errors made in attempts to measure total factor productivity without fully exploiting the economic theory underlying the social accounting concepts of real product and real factor input. We begin by eliminating errors of aggregation in combining investment and consumption goods and labour and capital services. We then eliminate errors of measurement in the prices of investment goods arising from the use of prices for inputs into the investment goods sector rather than outputs from this sector. We remove errors arising from the assumption that the flow of services is proportional to stocks of labour and capital by introducing direct observations on the rates of utilization of labour and capital stock. We present rates of growth that result from correct aggregation of investment goods and capital services. Finally, we give rates of growth that result from correcting the aggregation of labour services.

The rate of growth of input initially explains 52·4 per cent of the rate of growth of output. After elimination of aggregation errors and correction for changes in rates of utilization of labour and capital stock the rate of growth of input explains 96·7 per cent of the rate of growth of output; change in total factor productivity explains the rest. In the terminology of the theory of production, movements along a given production function explain 96·7 per cent of the observed changes in the pattern of productivity activity; shifts in the production function explain what remains.

This computation is based on the 1945-65 period, measuring total factor productivity peak to peak. If one were to choose a different set of years, the numerical results would be slightly different, but their main thrust would be the same. For example, starting with the Post-Korean peak year of 1953, the rate of growth of input initially explains only 37·3 per cent of the rate of growth of output. After all the corrections the rate of growth of input explains 79·2 per cent of the growth in output between 1953 and 1965, reducing the estimated rate of change in total factor productivity from 2·12 per cent per year to 0·72. We conclude that our hypothesis is consistent with the facts. If the economic theory underlying the measurement of real product and real factor input is properly exploited, the role to be assigned to growth in total factor productivity is small.

TABLE IX

Total output, input, and factor productivity, U.S. private domestic economy, 1945-65, *average annual rates of growth*

	Output	Input	Productivity
1. Initial estimates	3·49	1·83	1·60
Estimates after correction for:			
2. Errors of aggregation	3·39	1·84	1·49
3. Errors in investment goods prices	3·59	2·12	1·41
4. Errors in relative utilization	3·59	2·57	0·96
5. Errors in aggregation of capital services	3·59	2·97	0·58
6. Errors in aggregation of labour services	3·59	3·47	0·10

4.2. *Evaluation of past research*

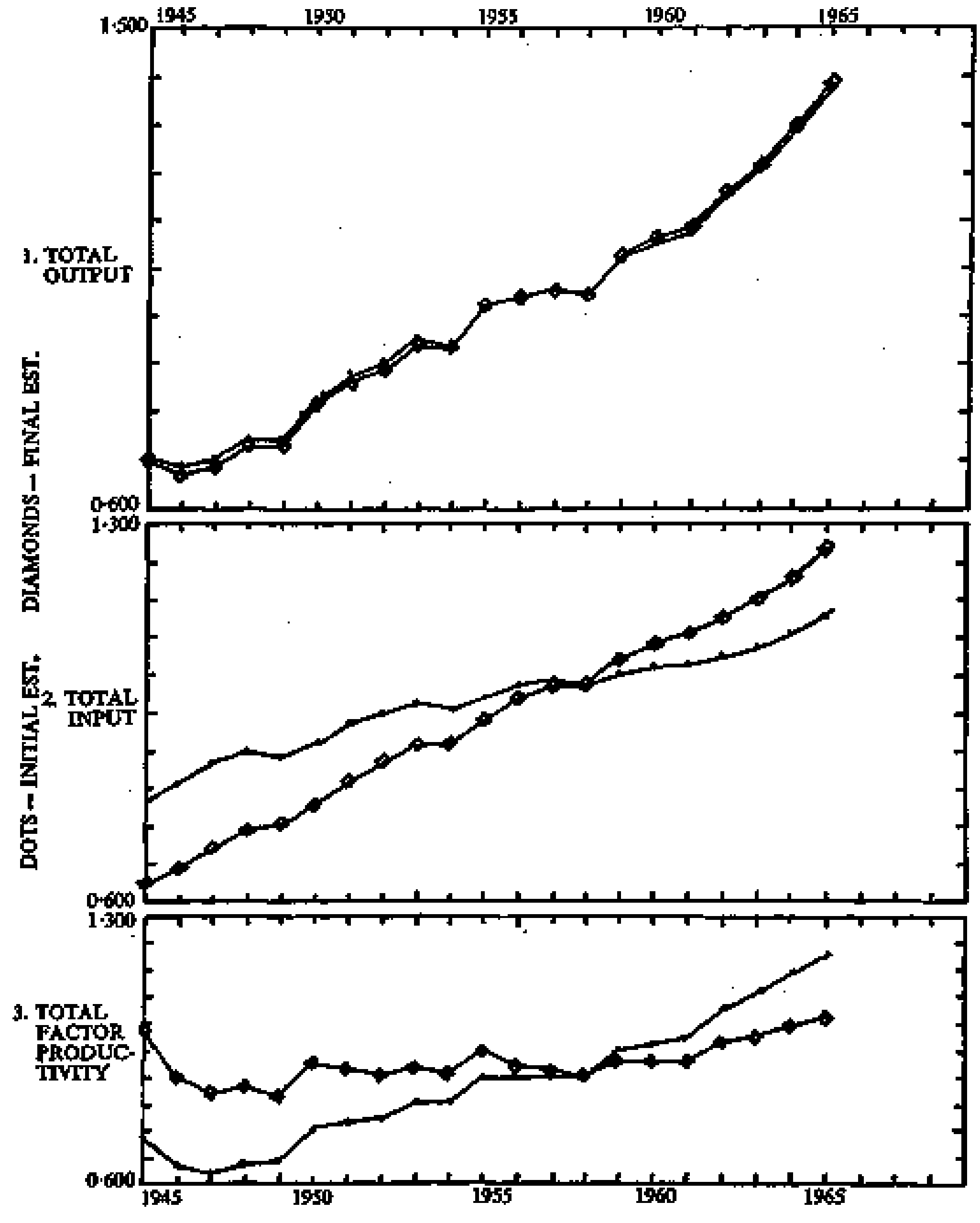
Our conclusion that most of the growth in total output may be explained by growth in total input is just the reverse of the conclusion drawn from the great body of past research on total factor productivity, the research of Schmookler [55], Mills [46], Fabricant [23], Abramovitz [2], Solow [61], and Kendrick [37]. These conclusions, stated by Abramovitz, are "... that to explain a very large part of the growth of total output and the great bulk of output *per capita*, we must explain the increase in output per unit of conventionally measured inputs. . . "[1]. This conclusion results from inadequacies in the basic economic theory underlying the social accounts employed in productivity measurements. The increase in output per unit of conventionally measured inputs is characterized by very substantial errors of measurement, equal in magnitude to the alleged increase in productivity. We have given a concrete and detailed list of errors of this type.

Our results differ from those of Denison [15] in that we correct changes in total factor productivity for errors in the measurement of output, capital services, and labour services, while Denison corrects only for errors in the measurement of labour services.

[1] Abramovitz [1, p. 776].

To get some idea of the relative importance of errors in the measurement of labour and errors in the measurement of output and capital, we may observe that the rate of growth of total factor productivity is reduced from 1·60 per cent per year to 0·10 per cent per year. Of the total reduction of 1·50 per cent per year errors in the measurement of output and capital account for 1·17 per cent per year while errors in the measurement of labour

INDEXES OF TOTAL OUTPUT, TOTAL INPUT AND TOTAL FACTOR PRODUCTIVITY (1958 = 1·0), U.S. PRIVATE DOMESTIC ECONOMY, 1945-1965



account for 0·33 per cent per year. We conclude that errors of measurement of the type left uncorrected by Denison are far more important than the type of errors he corrects.[1]

Our results suggest that the residual change in total factor productivity, which Denison attributes to Advance in Knowledge, is small. Our conclusion is not that advances in knowledge are negligible, but that the accumulation of knowledge is governed by the same economic laws as any other process of capital accumulation. Costs must be incurred if benefits are to be achieved. Although we have made no attempt to isolate the effects of expenditures on research and development from expenditures on other types of current inputs or investment goods, our results suggest that social rates of return to this type of investment are comparable to rates of return on other types of investment. Of course, our inference is indirect and a better test of this proposition could be provided by direct observation of private and social rates of return to investment in scientific research and development activities. Unfortunately, many of the direct observations on these rates of return available in the literature attribute all or part of the measured increase in total factor productivity to investment in research and development;[2] since these measured increases are subject to all the errors of measurement we have enumerated, satisfactory direct tests of the hypothesis that private and social rates of return to research and development investment are equal to private rates of return to other types of investment are not yet available.

Another implication of our results is that discrepancies between private and social returns to investment in physical capital may play a relatively minor role in explaining economic growth. Under the operational definitions of total factor productivity we have adopted, a positive discrepancy between social and private rates of return would appear as a downward bias in the rate of growth of input, hence an upward bias in the rate of growth of total factor productivity. The effects of such discrepancies are lumped together with the effects of other sources of growth in total factor productivity we have measured. The fact that the growth of the resulting index is small indicates that the contribution of investment to economic growth is largely compensated by the private returns to investment. This implication of our findings is inconsistent with explanations of economic growth such as Arrow's model of learning by doing [3], which are based on a higher social than private rate of return to physical capital.[3]

Of course, ours is not the first explanation of productivity change that does not rely primarily on discrepancies between private and social rates of return. An explanation of this type has been proposed by Solow [60], namely, embodied technical change. As Solow [59] points out, explanation of measured changes in total factor productivity as embodied technical change does not require discrepancies between private and social rates of return: " . . . the fact of expectable obsolescence reduces the private rate of return on saving below the marginal product of capital as one might ordinarily calculate it. But this discrepancy is fully reflected in a parallel difference between the marginal product of

[1] Errors in the aggregation of labour services account for 0·48 per cent per year, but this is offset by errors of measurement in the relative utilization of labour of −0·15 per cent per year so that the net correction for errors of measurement of labour is 0·33 per cent per year.

An alternative interpretation of our results may be provided by analogy with the conceptual framework for technical change discussed by Diamond [16]. Errors of measurement in the growth of labour services may be denoted labour-diminishing errors of measurement; capital-diminishing errors of measurement may be separated into embodied and disembodied errors. Errors in capital due to errors in the measurement of prices of investment goods are analogous to embodied technical change. Finally, some of the errors in measurement affect levels of output; these errors may be denoted output-diminishing errors of measurement.

A decomposition of total errors of measurement into labour-diminishing, capital-diminishing, embodied and disembodied, and output-diminishing is as follows: Labour-diminishing errors of measurement contribute 0·33 per cent per year to the initial measured rate of growth of total factor productivity. Embodied capital-diminishing errors contribute 0·28 per cent per year and disembodied capital-diminishing errors contribute 0·99 per cent per year. Finally, output-diminishing errors of measurement of 0·10 per cent per year must be set off against the input-diminishing errors totalling 1·60 per cent per year.

[2] See, for example, the studies of Minasian [47] and Mansfield [42].

[3] See Levhari [40, 41] for an elaboration of this point.

capital and the social rate of return on saving. So . . . the private and social rates of return coincide"[1]. In referring to "capital as one might ordinarily calculate it", Solow explicitly does not identify quality-corrected or "surrogate" capital with capital input and "surrogate" investment with investment goods output. In Solow's framework the marginal product of "surrogate" capital is precisely equal to the private and social rate of return on saving. The difference between Solow's point of view and ours is that the private and social rates of return are equal by definition in his framework, where the equality between private and social rates of return is a testable hypothesis within our framework.[2]

4.3. *Implications for future research*

The problem of measuring total factor productivity is, at bottom, the same as the estimation of national product and national factor input in constant prices. The implication of our findings is that the predominant part of economic growth may be explained within a conventional social accounting framework. Of course, precise measurement of productivity change requires attention to reliability as well as accuracy. Our catalogue of errors of measurement could serve as an agenda for correction of errors in the measurement of output and for incorporation of the measurement of input into a unified social accounting framework. Given time and resources we could attempt to raise all of our measurements to the high standards of the U.S. National Product Accounts in current prices. This could be done with some difficulty for rates of relative utilization of labour and capital stock and the prices of investment goods, which require the introduction of new data into the social accounts. The elimination of aggregation errors in measuring capital services and investment goods requires a conceptual change to bring these concepts into closer correspondence with the economic theory of production. The measurement of appropriate indexes of labour input, corrected for errors of aggregation, necessitates fuller exploitation of existing data on wage differentials by education, occupation, sex, and so on.

The most serious weakness of the present study is in the use of long-term trends in the relative utilization of capital and labour to adjust capital input and labour input to concepts appropriate to the underlying theory of production. As a result of discrepancies between these trends and year-to-year variations in relative utilization of capital and labour, substantial errors of measurement have remained in the resulting index of total factor productivity. Examination of any of the alternative indexes we have presented reveals substantial unexplained cyclical variation in total factor productivity. An item of highest priority in future research is to incorporate more accurate data on annual variations in relative utilization. Hopefully, elimination of these remaining errors will make it possible to explain cyclical changes in total factor productivity along the same lines as our present explanation of secular changes. Cyclical changes are very substantial so that even our secular measurements could be improved with better data. For example, the use of the period 1945-58, a peak in total factor productivity to a trough, reveals a drop in total factor productivity of nine per cent; the use of the period 1949-65, a trough to a peak, yields an increase in total factor productivity of eleven and a half per cent.

In compiling data on labour input we have relied upon observed prices of different types of labour services. Given a broader accounting framework it would be possible to treat human capital in a manner that is symmetric with our measurement of physical capital. Investment in human capital could be cumulated into stocks along the lines suggested by Schultz [56]. The flow of investment could be treated as part of total output. The rate of return to this investment could then be measured and compared with the rate of return to physical capital. Similarly, investment in scientific research and development could be separated from expenditures on current account and cumulated into stocks.

[1] Solow [59, p. 58-59].
[2] For further discussion of this point, see Jorgenson [35].

The rate of return to research activity could then be computed. In both of these calculations it would be important not to rely on erroneously measured residual growth in total output for measurement of the social return to investment.

It is obvious that further disaggregation of our measurements would be valuable in order to provide a more stringent test of the basic hypothesis that growth in output may be explained by growth in input. The most important disaggregation of this type is to estimate levels of output and input by individual industries. The statistical raw material for disaggregation by industry is already available for stocks of labour and capital and levels of output. However, data for relative utilization of labour and capital and for disaggregation of different types of labour and capital within industry groups would have to be developed. Once these data are available, it will be possible to estimate rates of return to capital for individual industries and to study the effects of the distribution of productive factors among industries along the lines suggested by Massell [43]. The fact that past observations do not reveal significant changes in productivity does not imply that the existing allocation of productive resources is efficient relative to allocations that could be brought about by policy changes. In such a study it might be useful to extend the scope of productivity measurements to include the government sector. This would be particularly desirable if educational investment, which is largely produced in that sector, is to be incorporated into total output.

Finally, our results suggest a new point of departure for econometric studies of production function at every level of aggregation. While some existing studies [29, 30] employ data on output, labour, and capital corrected for errors of measurement along the lines we have suggested, most estimates of production functions are based on substantial errors of measurement. Econometric production functions are not an alternative to our methods for measuring total factor productivity, but rather supplement these methods in a number of important respects. Such production functions provide one means of testing the assumptions of constant returns to scale and equality between price ratios and marginal rates of transformation that underlie our measurement. A complete test of the hypothesis that growth in total output may be explained by growth in total input requires the measurement of input within a unified social accounting framework, the measurement of rates of return to both human and physical capital, further disaggregation, and new econometric studies of production functions. A start has been made on this task, but much interesting and potentially fruitful research remains to be done.

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STATISTICAL APPENDIX

1. As our initial estimate of output we employ gross private domestic product which is defined as gross national product less gross product, general government, and gross product, rest of the world, all in constant prices of 1958. These data are obtained from the U.S. national accounts. Our second estimate of output requires data on gross private domestic investment and gross private domestic consumption, defined as gross private domestic product less gross private domestic investment, in both current and constant prices of 1958. These data are also obtained from the U.S. national accounts.

As our initial estimate of labour input we employ private domestic persons engaged, defined as persons engaged for the national economy less persons engaged, general government, and persons engaged, rest of the world. These data are obtained from the U.S. national accounts [48]. Our initial estimate of capital input is obtained by the perpetual inventory method based on double declining balance estimates of replacement. For structures and equipment the lifetimes of individual assets are based on the " Bulletin F lives " employed by Jaszi, Wasson and Grose [33]. Data for gross private domestic investment prior to 1929 are unpublished estimates that underlie the capital stock estimates of Jaszi, Wasson and Grose [33]. For inventories and land, the initial values of capital stock in constant prices of 1958 are derived from Goldsmith [25]. The stock of land in constant prices is assumed to be unchanged throughout the period we consider. Estimates of the value of land in current prices are obtained from Goldsmith [25].

The estimates of gross private domestic investment are subsequently revised by introducing alternative deflators to those employed in the U.S. national accounts. These deflators are given in Table III of the text. Gross private domestic consumption is left unchanged in this calculation. We compute stocks of land, structures, residential and non-residential, equipment, and inventories separately for each set of deflators. The basic formula is:

$$K_{t+1} = I_t + (1-\delta)K_t, \qquad \ldots(14)$$

where I_t is the value of gross private domestic investment for each category in constant prices. The initial (1929) value of capital stock in constant prices of 1958 and the depreciation rates are as follows:

	National accounts deflators		Alternative deflators	
	K_{1929}	δ	K_{1929}	δ
Land	254,700	0	254,700	0
Structures				
Residential	183,234	0·0386	162,708	0·0384
Non-residential	163,205	0·0513	142,670	0·0509
Equipment	74,851	0·1325	51,701	0·1226
Inventories	48,504	0	48,504	0

2. In dropping the assumption that services are proportional to stock for both labour and capital, we require data on hours/man and hours/machine. The data on hours/man are derived from Kendrick's data on man-hours in the U.S. private domestic economy, extended through 1965.

To estimate hours/machine we first estimate the relative utilization of electric motors in manufacturing. Estimates have been given by Foss [24] for 1929, 1939 and 1954. We have updated these estimates to 1962. The basic computation is given in Table X. The 1954 data and the basic method of computation are taken from Foss [24, Table II, p. 11]. The 1954 data differ from the figures given by Foss due to a revision of the 1954 horsepower data by the Bureau of the Census and omission of the "fractional horsepower motors" adjustment. The latter, applied to both 1954 and 1962, would not have affected the estimated change in relative utilization. The horsepower data for 1962 and 1954 are from the 1963 *Census of Manufactures* [7], "Power Equipment in Manufacturing Industries," MC63(1)-6. Consumption of electric energy is taken from the 1962 *Survey of Manufactures* [11], Chapter 6. The 1962 total (388·2) is reduced by the consumption of electric power for nuclear energy (51.5) as shown in Series S81-93 of Bureau of the Census, *Continuation to 1962 of Historical Statistics of the U.S.* [9].

3. To estimate service prices for capital from the formula (11) given in the text we require data on the tax structure and on the rate of return. The variable u, the rate of direct taxation, is the ratio of corporate profits tax liability to total net private property income. These data are from the U.S. national accounts. The variable v, the proportion of return to capital allowable as a charge against income for tax purposes, is the ratio of

private domestic net interest to the after tax rate of return, r, multiplied by the current value of capital stock. Private domestic net interest is net interest less net interest for the rest of the world sector. These data are taken from the U.S. national accounts. We discuss estimation of the after tax rate of return below. The current value of capital stock is the sum of stock in land, structures, equipment, and inventories. Each of the four components is the product of the corresponding stock in constant prices of 1958, multiplied by the investment deflator for the component. Finally, the variable w, the proportion of replacement allowable for tax purposes, is the ratio of capital consumption allowances to the current value of replacement. Capital consumption allowances are taken from the U.S. national accounts. The current value of replacement is the sum of replacement in

TABLE X

Relative utilization of electric motors, manufacturing, 1954 and 1962

	Unit	1954	1962
1. Horsepower of electric motors, total	Thousand horsepower	91,505	126,783
2. Available kilowatt-hours of motors (line 1 × 7261)	Billions of kilowatt-hours	664·4	920·6
3. Electric power actually consumed, all purposes	Billions of kilowatt-hours	222·1	336·7
4. Per cent power used for electric motors	...	64·6	65·6
5. Power consumed by motors (line 3 × line 4)	Billions of kilowatt-hours	143·5	220·9
6. Per cent utilization (line 5/line 2 × 100)	...	21·6	24·0
7. Number of equivalent 40 hour weeks (line 6 × 4·2/100	...	0·907	1·008
8. Index	1954 = 100	100·0	111·1

Line 2: The adjustment is derived as follows: It is assumed "that each electric motor could work continuously throughout the year . . ., 8760 . . .. Horsepower hours are converted to kilowatt-hours; . . . 1 horsepower-hour = 0·746 kilowatt hours. The result [is] . . . adjusted upward by dividing through 0·9, since modern electric motors have an efficiency of approximately 90 per cent. . . ." Foss [23, p. 11]. 8760 × 0·746/0·9 = 7261.

Line 4: Per cent power used for electric motors in 1962 computed using the industry distribution in 1945 given by Foss [24] in his Table I, and the 1962 consumption of total electric power by industries from the 1962 *Survey of Manufacturers* [1, Chapter 6].

Line 7: There are 4·2 forty-hour shifts in a full week of 168 hours.

current prices for structures and equipment. Replacement in current prices is the product of replacement in constant prices of 1958 and the investment deflator for the corresponding component. Replacement in constant prices is a by-product of the calculation of capital stock by formula (14) given above. Replacement is simply δK_t, where K_t is capital stock in constant prices.

To estimate the rate of return we define the value of capital services for land, structures, equipment and inventories as the product of the service price (11) and the corresponding stock in constant prices. Setting this equal to total income from property, we solve for the rate of return. Total income from property is gross private domestic product in current prices less private domestic labour income. Private domestic labour income is private domestic compensation of employees from the U.S. national accounts multiplied by the ratio of private domestic persons engaged in production to private domestic full-time equivalent employees, both from *The National Income and Product Accounts of the United States*, 1929-1965 [49]. This amounts to assuming that self-employed individuals have the same average labour income as employees.

The final formula for the rate of return is then the ratio of total income from property less profits tax liability less the current value of replacement plus the current value of capital gain to the current value of capital stock. The current value of capital gain is the sum of capital gains for all assets; the capital gain for each asset is the product of the rate of growth of the corresponding investment deflator and the value of the asset in constant prices of 1958.

4. The basic sources of data underlying Table VII of the text are summarized in Tables XI and XII. Table XI presents estimates of the distribution of the male labour force by school years completed for 1940, 1948, 1952, 1957, 1959, 1962 and 1964. These data are taken from various issues of the *Special Labor Force Reports* [5] and *Current*

TABLE XI

Civilian labour force, males 18 to 64 years old, by educational attainment per cent distribution by years of school completed

School year completed	1940	1948	1952	1957	1959	1959†	1962†	1965†
Elementary 0-4	10·2	7·9	7·6	6·3	5·5	5·9	5·1	4·3
5-6 or 5-7*	10·2	7·1	6·6 11·6	11·4	10·4	10·7	9·8	8·3
7-8 or 8*	33·7	26·9	25·1 20·1	16·8	15·6	15·8	13·9	12·7
High School 1-3	18·3	20·7	19·4	20·1	20·7	19·8	19·2	18·9
4	16·6	23·6	24·6	27·2	28·1	27·5	29·1	32·3
College 1-3	5·7	7·1	8·3	8·5	9·2	9·4	10·6	10·6
4+ or 4	5·4	6·7	8·3	9·6	10·5	6·3	7·3	7·5
5+	...	...	...	...	...	4·7	5·0	5·4

SOURCE: The basic data for columns 1, 3, 4, 5 and 6 are taken from U.S. Department of Labor, *Special Labor Force Report* [5], No. 1, "Educational Attainment of Workers, 1959". The 5-8 years class is broken down into the 5-7 and 8 (5-6 and 7-8 for 1940, 1948, and 1952) on the basis of data provided in *Current Population Report* [10], Series P-50, Nos. 14, 49 and 78. The 1940 data were broken down using the 1940 *Census of Population* [8], Vol. III, Part I, Table 13. The 1952 breakdown for translating the 5-7 class into 5-6 and 7-8 was done using the information on the educational attainment of all males by single years of school completed from the 1950 *Census of Population* [8], Detailed Characteristics, U.S. Summary. The 1962 data are from *Special Labor Force Report* [5], No. 30, and the 1965 figures are from *Special Labor Force Report* [11], No. 65, "Educational Attainment of Workers, March 1965".

* 5-6 and 7-8 for 1940, 1948 and the first part of 1952, 5-7 and 8 thereafter.

† Employed, 18 years and over.

TABLE XII

Mean annual earnings of males, 25 years and over by school years completed, selected years

School year completed	1939	1949	1956	1958	1959	1963
Elementary 0-4	665	1724	2127	2046	2935	2465
5-6 or 5-7	900	2268	2927	2829	4058	3409
7-8 or 8	1188	2693 2829	3732	3769	4725	4432
High School 1-3	1379	3226	4480	4618	5379	5370
4	1661	3784	5439	5567	6132	6588
College 1-3	1931	4423	6363	6966	7401	7693
4+ or 4	2607	6179	8490	9206	9255	9523
5+	...	...	...	...	11,136	10,487

SOURCE: Columns 1, 2, 3, 4, H. P. Miller [45, Table 1, p. 966]. Column 5 from 1960 *Census of Population* [8], PC(2)-7B, "Occupation by Earnings and Education". Column 6 computed from *Current Population Reports* [10], Series P-60, No. 43, Table 22, using midpoints of class intervals and $44,000 for the over $25,000 class. The total elementary figure in 1940 broken down on the basis of data from the 1940 *Census of Population* [8]. The "less than 8 years" figure in 1949 split on the basis of data given in H. S. Houthakker [32]. In 1956, 1958, 1959 and 1963, split on the basis of data on earnings of males 25-64 from the 1959 1-in-a-1000 Census sample. We are indebted to G. Hanoch for providing us with this tabulation.

Earnings in 1939 and 1959; total income in 1949, 1958 and 1963.

Population Reports [10], with some additional data from the 1940, 1950 and 1960 *Census of Population* [8] used to break down several classes into sub-classes. We could have used data from the 1950 and 1960 Censuses on educational attainment. The increase in the number of links did not seem to offset the decrease in comparability that would be introduced by the use of different sources of data. Table II presents estimates of the mean incomes of males (25 years and over) for these classes. These data are largely taken from Miller [45], supplemented by Census and *Current Population Reports* [10] data. Table VI of the text presents the relative incomes, the first differences of the educational distribution, and the computation of an appropriate index of the change in the average education per man.

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By EDWARD F. DENISON

Some Major Issues in Productivity Analysis: An Examination of Estimates by Jorgenson and Griliches

The Office of Business Economics has been asked by several of the principal users of its data to supplement its established series on national output and its composition (GNP) by consistent measures of factor inputs, so as to facilitate the analysis of economic growth. The OBE is responsive to these requests and considers the preparation of measures of factor inputs an appropriate extension of its work on the national economic accounts. The estimates of business capital stocks and some other studies that have been published in the SURVEY OF CURRENT BUSINESS are important steps leading to the preparation of factor input measures.

The conceptual and statistical problems that are involved in the measurement of factor inputs are unusually difficult, however, and OBE believes that some discussion of these problems is called for before it engages itself to prepare the measures. To elicit such a discussion is a major purpose of publishing this article.

In this study, Edward F. Denison, one of the outstanding experts in the analysis of economic growth, provides a searching comparison of the concepts and statistical procedures that he considers appropriate for input measurement with those recently proposed by the eminent econometricians, Dale W. Jorgenson and Zvi Griliches. The Jorgenson-Griliches proposals differ sharply from those set forth by Denison, and also by many others who have done research in this field. For the convenience of the reader, the *Review of Economic Studies* article in which the Jorgenson-Griliches proposals appeared is reprinted—with some corrections by the authors—in this issue of the SURVEY.

These differences in concepts and procedures yield strikingly different conclusions. According to Denison, a substantial part of the postwar growth of national output has been due to an increase in productivity; according to Jorgenson-Griliches almost all of the increase has been due to an increase in factor inputs.

The issues raised by these opposing conclusions are not only important from the standpoint of basic research but are also likely to have far-reaching implications for the formulation of private and public policies directed at the promotion of economic growth. We believe that the publication of the Denison article and of a reply to it by Jorgenson and Griliches in a later issue of the SURVEY will be of substantial interest to all those concerned with economic growth.

IN a recent article, "The Explanation of Productivity Change," Professors Dale W. Jorgenson and Zvi Griliches found that increases in labor and capital input were responsible for almost all postwar growth in the United States [1]. They concluded that output per unit of input contributed little to the growth rate of output—only 0.10 percentage points, to be exact. This estimate contrasts with much larger amounts obtained in virtually all other studies. I arrived at 1.37 percentage points in *Why Growth Rates Differ: Postwar Experience in Nine Western Countries* (written with the assistance of Jean-Pierre Poullier) [2].

This review is a response to repeated requests to comment upon the article by Jorgenson and Griliches.[1] Do their estimates differ so much from mine because of differences in the time period analyzed, in the definition of output, or in the sector of the economy covered? Does the discrepancy reflect a mere difference in classifying growth sources into those regarded as increasing input and those regarded as raising output per unit of input? Or is it due to differences in statistical procedures? What are the differences in our procedures, what are their quantitative effects, and whose, in my opinion, are preferable? In this article, all of these questions are discussed.

To decompose the discrepancy in results, it is necessary to examine many aspects of the estimates. Section I of this review measures the effects of differences in time period, definition of output, and scope of the economy analyzed, and section II examines a minor difference in procedure. After allowance for these differences, most of the large discrepancy between our measures of output per unit of input remains. Our statistical measures of total output diverge because different price indexes are used for deflation; the effect is examined in section VI. Differences between our total input series for the sector of the economy analyzed by Jorgenson and Griliches are much larger. The input series differ because of (a) differences in the weights we use to combine individual inputs and (b) differences in the way we measure each individual input. In sections III and IV, I consider the change that would be introduced in my series, given my individual input measures, if the Jorgenson-Griliches weights were used. In sections V, VII, and VIII, I measure the effects upon their series, given their weights, of using their measure for each input in place of mine. The two preceding sentences must be qualified

NOTE.—Dr. Denison is Senior Fellow, The Brookings Institution, Washington, D.C. The views expressed in this article are those of the author and do not purport to represent the views of the other staff members, officers, or trustees of The Brookings Institution.

1. Its preparation was the occasion of rather extended communication among us, in the course of which Professors Jorgenson and Griliches clarified certain of their procedures, provided some unpublished data needed for comparison of our estimates, and offered suggestions on presentation. This assistance helped me to isolate the differences between our procedures and focus my discussion on these differences. It is acknowledged with gratitude.

I also benefited greatly from discussions of a draft of this review with George Jaszi, and of certain sections with Murray F. Foss, Guy V. G. Stevens, and Allan H. Young.

by noting, as I shall at the appropriate points, that lack of data necessitated some departures from this plan. In section IX, I provide a table that summarizes the results of the preceding sections and thus reconciles our output per unit of input series.

An equally important purpose of this article is to examine the merits of alternative procedures. In most sections I therefore discuss differences in procedure that happen not to be important sources of discrepancy in our series during the particular time period discussed as well as those that are, and in sections IX and X offer some general observations.

The section of most general interest may well be section VII, in which I examine the Jorgenson-Griliches capital utilization adjustment. I try there to nudge the theory of growth analysis forward a little. In addition, their capital utilization adjustment is the largest single reason that our output per unit series diverge.

I. Time Period, Definition of Output, and Scope of Economy Covered

THE Jorgenson-Griliches summary result, that output per unit of input contributed only 0.10 percentage points to a 3.59 percent a year increase in output, refers to the 1945–65 period. Use of 1945 as a starting point minimizes their figure. From 1948 to 1965 Jorgenson and Griliches obtain a growth rate of output per unit of input of 0.74.[2] Almost all of this increase came before 1950 and after 1961; the growth rate of their output per unit of input series was 0.01 from 1950 to 1961 and 2.01 from 1961 to 1965 [calculated from 1, table VIII]. Cyclical movements contribute to the difference between these periods, but even so the contrast is remarkable.

My summary estimate, that the increase in output per unit of input contributed 1.37 points to the growth rate, refers to the period from 1950 to 1962. For this timespan, Jorgenson and Griliches obtain 0.30, as against 0.10 for 1945–65. Thus, the difference in time period is responsible for 0.20 points of the difference between our summary estimates. Our estimates for 1950–62 and two subperiods are contrasted in the first two rows of the following table. The third row [from 2, table 21–1] shows my estimates after adjustment to eliminate, as best I could, the effects of differences among terminal years in the intensity of demand (i.e., short-term changes in intensity of utilization of employed resources).

	1950–62	1950–55	1955–62
Unadjusted:			
Jorgenson-Griliches	0.30	0.42	0.22
Denison	1.37	1.93	.97
Adjusted:			
Denison	1.41	1.54	1.21

The Jorgenson-Griliches series refers to real gross national product per unit of input in the private domestic economy; mine, to real national income (also called net national product valued at factor cost) per unit of input in the economy as a whole.

The reason I chose to analyze the growth of net rather than gross product is both fundamental and conventional.

"Insofar as a large output is a proper goal of society and objective of policy, it is net product that measures the degree of success in achieving this goal. Gross product is larger by the value of capital consumption. There is no more reason to wish to maximize capital consumption—the quantity of capital goods used up in production—than there is to maximize the quantity of any other intermediate product used up in production, such as, say, the metal used in making television sets. It is the television sets, not the metal or machine tools used up in production, that is the objective of the production process" [2, pp. 14–15].

Jorgenson and Griliches confine discussion of their choice of gross product to a single sentence. "Exclusion of depreciation on capital introduces an entirely arbitrary distinction between labour input and capital input, since the corresponding exclusion of depreciation of the stock of labour services is not carried out" [1, p. 256]. (They also cite an article by Domar, but it contains no reference to depreciation of labor.) Their statement is too brief to allow much discussion, particularly since Jorgenson and Griliches do not specify how they would depreciate labor. I am not aware of a definable labor counterpart to capital depreciation as a component of GNP that there is no advantage in increasing because it is not wanted—feeding, clothing, and housing children surely do not fall into this category—but if there be such, the appropriate remedy would be to change the measures of output and labor earnings.

I do not wish to pursue this subject further in this article, but must provide a statistical reconciliation of our estimates. This is facilitated by the fact that, sheerly by chance, conversion of my estimate of output per unit of input in the 1950–62 period to their concepts would scarcely change it because the difference in definition of output happens to be offset by the difference in the scope of the economy covered. The explanation is as follows:

(a) My output series refers to national income, or net national product (NNP) valued at factor cost, measured in 1958 prices. The Jorgenson-Griliches output series refers to gross national product valued at market prices, measured in 1958 prices. The choice between factor cost and market price weights to combine the components of product does not affect comparability of our results, but that between gross and net

2. National accountants would not draw inferences about postwar growth trends from an analysis beginning before 1948, at the earliest, because elimination of price controls distorted the real output measure in 1945–48, and because—in the case of 1945—of the great difference from later years in the composition of output. In addition, special aspects of postwar reconversion greatly affected the 1945–48 period.

product does. The *absolute* increase in the value of gross product at 1958 factor cost is equal to the increase in net product at 1958 factor cost plus the increase in depreciation valued in 1958 prices. Each year, the change in output per unit of input (and every other growth source except depreciable capital) contributes the same absolute amount to the increase in real GNP at factor cost as to real NNP at factor cost. (Depreciable capital contributes to the increase in real GNP an amount equal to its contribution to the increase in real NNP plus the absolute increase in depreciation at constant prices.) But the same absolute amount contributed by output per unit of input yields a smaller percentage increase in GNP at factor cost than in NNP because the value of GNP is bigger than that of NNP—in 1950 by 11.6 percent, according to my estimates. Hence, output per unit of input contributed less to the growth rate of GNP when measured in percentage points. For 1950–62, my estimates yield a contribution of output per unit of input to the growth rate of GNP of 1.24 percentage points as against 1.37 to the growth rate of NNP.[3]

(b) My output estimates refer to the economy as a whole; the Jorgenson-Griliches estimates, to the private domestic economy. Thus, the latter exclude the net inflow of property income from abroad and GNP originating in general government. However, my estimates imply *no* increase in output per unit of input in the sectors they exclude.[4] The *absolute* contribution of the increase in output per unit of input to the increase in output is therefore the same in the sector covered by the Jorgenson-Griliches estimates as in the whole economy. Because the level of private domestic GNP was smaller than that of total GNP, the contribution of output per unit of input to its growth rate is proportionately larger; it is 1.38.[5]

This is practically the same as my original figure of 1.37; adjustments (a) and (b) are almost exactly offsetting.[6] Thus, differences in definition and scope of output together account for none of the difference between our 1950–62 estimates of the contribution of output per unit of input.[7]

II. Divisia Indexes

JORGENSON and Griliches devote considerable attention in their article to their use of Divisia indexes (which are averages of growth rates, with frequent changes in weights) in their measurement of input and output. I shall not discuss the alleged theoretical superiority of Divisia indexes, but simply note that their substitution has no effect upon the comparisons. When Jorgenson and Griliches introduce them in moving from their table I to table II, the movement from 1950 to 1962 of their series for output, input, and factor productivity is almost unaffected. Indeed, introduction of Divisia indexes has no appreciable effect at other dates except at the very beginning of their period, when price and output patterns were distorted. Moreover, my own procedures for combining inputs are substantially equivalent to the use of Divisia indexes.

III. The Input Weights: Total Labor vs. Total Capital and Land

TO calculate changes in total input, weights to combine the various types of input are required. Our weights, though different, share two characteristics that distinguish them from those of some other investigators. First, we each set the sum of our input weights equal to 100 percent (or 1). This has the effect of classifying gains from economies of scale as a contribution of output per unit of input to the growth of output.[8] Second, we each use the shares of labor, and of capital and land, in total earnings from production as weights to combine these broad types of input, and rely upon data from the national accounts to estimate these shares.[9]

Our actual weights differ as a result of differences in the scope and definition of our output measures and of differences in our estimating procedures. The latter contribute to the discrepancy between our results for growth of GNP per unit of input. During the postwar periods analyzed, capital-land input increased more than labor input so that the greater the weight attached to capital-land, the more a measure of

3. For consistency with OECD estimates, my GNP figures include a small amount for government capital consumption. This comes out again when I move to the private domestic economy in adjustment (b).

4. The entire increase in net property income from abroad is counted as a contribution of capital. Real GNP in general government is measured on the assumption that output per person employed does not change (this statement is only approximately accurate), and for this reason I used procedures that have the effect of measuring inputs in general government by employment [2, pp. 157-158]. Hence, no change in output per unit of input occurs in general government.

5. As indicated in section IV, my estimates imply that the contribution to the growth rate of net product at factor cost in the private domestic sector was 1.51.

6. This implies, of course, that the levels of total national income and private domestic GNP (both measured in 1958 prices at factor cost) happened to be almost the same at the start of the period (1950).

7. In measuring the effects of differences between us in concepts, scope, or procedures for this review, I often shorten the calculations by using average weights or rates for the period examined even though we each subdivide the periods in our calculations. The results are accurate enough for the purpose at hand.

8. Throughout this review, I ignore as of no quantitative importance the fact that, in presenting the contributions of the sources to the growth rate, I allocated to output per unit of input 0.01 percentage points of an interaction term. Jorgenson and Griliches do not present contributions as such and hence omit this term, but with their estimates nothing would be allocated to productivity in any case. I also ignore rounding discrepancies that cause their growth rate of output to exceed the sum of the growth rates of input and output per unit of input at intermediate points in their analysis by small amounts varying up to 0.[illegible] (as presented in their table IX).

9. My reasons for using income shares are stated in 2, chapter 4.

total input increases and the less output per unit of input increases.

Differences related to scope and definition

The weights used in my study refer to the shares of labor and capital-land in total national income. I measure labor earnings as the sum of (1) the compensation of employees and (2) a portion (about three-fifths) of proprietors' income; this portion is derived on the assumption that the labor share of national income originating in proprietorships and partnerships is the same as the labor share of national income originating in nonfinancial corporations [2, p. 37]. My estimate of the total earnings of capital and land is equal to the sum of the following items: the remainder (about two-fifths) of proprietors' net income; corporate profits (before tax) and inventory valuation adjustment; the rental income of persons; and net interest. The labor share plus the capital-land share equals national income. (Whatever is not earned by labor is counted as earnings of capital and land despite the fact that "pure" profit—whether a return to entrepreneurship or monopoly profit—is included.)[10] Depreciation is revalued at replacement cost in the computation of corporate and noncorporate earnings and rental income, and of total national income.[11] On the average in the 1950–62 period, labor earnings represented 78.6 percent and capital and land earnings 21.4 percent of total national income.[12] These percentages are shown in line 1 of the following table. The remainder of the table will help the reader follow the rest of this discussion.

	Labor share	Property share
Denison labor estimates:		
1. Whole economy, national income	78.6	21.4
2. Private domestic economy, national income	74.7	25.3
3. Private domestic economy, GNP at factor cost	67.2	32.8
Jorgenson-Griliches labor estimates:		
4. Private domestic economy, GNP at factor cost	70.8	29.2
5. Private domestic economy, GNP at market prices	63.8	36.2

The Jorgenson-Griliches analysis is confined to the private domestic sector. My results imply that labor earnings averaged 74.7 percent and capital and land earnings 25.3 percent of national income in this sector. Jorgenson and Griliches analyze the growth of gross rather than net output; this obviously calls for a difference in procedure somewhere in the calculations. One acceptable possibility is to include depreciation with the earnings of capital and land in the derivation of weights, and this is what Jorgenson and Griliches do.[13] If depreciation is added to national income and to the capital-land share, and the percentages are recomputed, my estimates indicate that labor earnings averaged 67.2 percent of gross domestic product at factor cost in 1950–62 and that capital-land earnings together with depreciation averaged 32.8 percent. (These figures are unaffected by the method of measuring depreciation.) These shares, shown in line 3 of the table, differ from those in line 1 for conceptual reasons. Their use by Jorgenson and Griliches to analyze gross private product would have introduced little or no discrepancy between their estimate of output per unit of input and that which I derived in section I after allowance for differences in the definition and scope of our output measures.

Differences due to estimating procedures

The Jorgenson-Griliches weights differ from these for two reasons. First, although their estimate of labor earnings, like mine, equals compensation of employees plus a portion of proprietors' income, they obtain the latter by a different procedure. They assume that labor earnings of proprietors are equal to the number of proprietors (exclusive of unpaid family workers) times compensation per fulltime equivalent employee in the private domestic economy [1, p. 278]. This procedure allocates approximately all of proprietors' income to labor and none to capital and land. The labor share obtained by this procedure averages 70.8 percent, and the capital-land share 29.2 percent, of private domestic GNP at factor cost instead of 67.2 and 32.8, the percentages at which I arrive. My allocation of proprietors' income seems to me the more reasonable, but admittedly both procedures have substantial precedent. In the nature of the case, there is no way to check the results directly. Their use of a larger estimate of labor earnings would, in itself, lead Jorgenson and Griliches to a *higher* estimate of the contribution of output per unit of input to growth than I obtain. However, it is much more than offset by what I regard as an error in their derivation of capital-land earnings.

Jorgenson and Griliches state in their statistical appendix [1, p. 278] that "total income from property is gross private domestic product in current prices less private domestic labour income." Gross private domestic product was valued at market prices in their calculation. This means that Jorgenson and Griliches count indirect business tax liability minus "subsidies less current surplus of government enterprises" and plus business transfer payments and the "statistical discrepancy" in the national accounts as earnings of capital and land. Jorgenson and Griliches inform me that this inclusion was intentional, not an oversight. Inclusion of these items in the earnings of capital and land raises their capital-land share from 29.2 percent to 36.2 percent, or by almost one-fourth, and lowers their labor share from 70.8 to 63.8.[14] (These shares, shown in row 5 of the preceding text table, were computed from annual

10. Since Jorgenson and Griliches do the same, this does not cause our estimates to diverge.

11. The estimates are based on use of Bulletin F lives and straight-line depreciation. They were prepared before the results of the latest OBE capital stock study for nonresidential structures and equipment became available.

12. I do not actually use weights for the period as a whole in calculations, nor do Jorgenson and Griliches. I use weights for three subperiods, and they change weights annually. The averages provide a convenient summary.

13. This procedure is not necessarily exactly equivalent to that which I used in section I above to adjust my estimates to a gross product basis, but any difference in the end result for output per unit of input is probably trivial.

14. It also has the effect of including indirect taxes, and the other reconciliation items mentioned, in profits after tax in the numerator of the "implicit rate of return after taxes" that Jorgenson and Griliches show in table VI, column 4, of their article. Their article gives no hint of this peculiar definition of an after tax rate of return. I doubt that many readers of their article can be aware of it.

figures given me by Jorgenson and Griliches.)

The principal item at issue, quantitatively, is indirect business tax liability. Jorgenson and Griliches do not explain why they include indirect business taxes in their weights or why, if they are to be included, there is more reason to add them to capital-land earnings than to labor earnings. Possible reasons for their procedures are hard to visualize, and I can only speculate as to what they may have had in mind.

The fact that Jorgenson and Griliches are analyzing the growth of gross product valued at market prices (which, viewed from the "income side," includes indirect taxes), rather than gross product valued at factor cost, surely necessitates no difference in weights. Share weights are used as estimates of the relative response (elasticity) of output to changes in labor input and to capital-land input; for example, use of weights of 30 percent for capital and land and 70 percent for labor to analyze gross product growth would imply that a given percentage increase in every type of capital-land input raises gross product by three-sevenths as large a percentage as does the same percentage increase in every type of labor input. There is no systematic reason for the percentage response of gross product valued at market prices to differ from the percentage response of gross product at factor cost.[15]

Possibly Jorgenson and Griliches mean to challenge the classification of indirect taxes as indirect. The income division that is appropriate for use as weights is the distribution of earnings that would prevail in the absence of taxes, *taking as given* the existing quantities of each input in the sector and period analyzed. To approximate this distribution, analysis is required of what is often called "shortrun" tax incidence (to distinguish it from analysis of incidence when any impact of taxes on the quantities of factors is taken into account). My use of the classification of taxes followed in the national accounts thus implies the following assumptions. First, that personal income and inheritance taxes (and various licenses, minor taxes, and nontax receipts of governments that are classified as personal) do not alter the distribution of earnings before taxes; hence, they need not be deducted from before-tax shares to achieve the desired distribution. Second, that the "shortrun" incidence of payroll taxes is on labor earnings; hence, labor earnings should be measured inclusive of payroll taxes. Third, that the "shortrun" incidence of corporate profit tax accruals is on corporate profits; hence, corporate profits should be measured inclusive of corporate profits taxes. Fourth, that the incidence of taxes classified as indirect is on no particular type of income and their presence does not alter relative shares measured exclusive of such taxes. Taxes classified as indirect, and the average percentage of total "indirect business tax and nontax accruals" represented by each type in 1950–62, are: sales and excise taxes and customs duties, 55 percent; property taxes, 33 percent; business motor vehicle licenses, 2 percent; other business taxes, 7 percent; business nontaxes, 3 percent.

No one supposes this classification of taxes to be precise. For example, I have myself suggested that at least the portion of the corporate income tax that is levied on regulated utilities probably is passed on in higher prices, causing my capital-land share to be overstated relative to labor. But, with some allowance for offsets, I have regarded the national accounts classification as acceptable.

If Jorgenson and Griliches count indirect taxes as earnings of capital and land because of incidence considerations, this implies that they accept the first three assumptions listed above and reject the fourth in favor of an assumption that the shortrun incidence of indirect taxes rests on capital and land.

For one tax classified as indirect, that on real property, this assumption may be preferable.[16] Indeed, in the context of considering the effect of taxes on the allocation of resources among sectors of the economy, I have myself suggested that one should not consider the impact of the corporate income tax, which bears only on the corporate sector, without simultaneously considering the property tax, which bears most heavily on the principal noncorporate sectors of the private economy: housing and farming [3, pp. 186–187]. It is plausible to argue that neither tax is shifted in the short run. But I see no possible reason to suppose that the short-term incidence of the other components of indirect tax and nontax liability rests on capital and land. These represent the bulk of the category, so I regard addition of indirect taxes to capital-land earnings as mainly an error.[17]

Although counting the difference between factor-cost and market prices as property income raises the Jorgenson-Griliches capital-land share of private domestic GNP by 7.0 percentage points in 1950–62, their actual weight averages only 3.4 percentage points higher than the weight implied by my estimates (with depreciation added) because of their smaller allocation of proprietors' income to property income.

My own estimate of output per unit of input is only moderately sensitive to differences in weights of this magnitude. If I were to substitute their weights for mine, my estimate of the contribution of output per unit of input would be lowered by about 0.08 percentage points.[18] I shall use this number to measure the difference in our results that is due to differences in our division of the weights between labor and capital-land as a whole. However, it should be noted that the Jorgenson-Griliches estimates are much more sensitive than mine to differences in weights because they estimate the

15. The movement over time of gross product at 1958 market prices differs from that of gross product at 1958 factor cost only if the composition of output shifts toward or away from products that were taxed (or subsidized) at above- or below-average rates in 1958. Any difference in movement is not related to share weights in the economy as a whole. (In 2, pp. 15–16, I suggest that if, in the output measure whose growth is analyzed, the components of output are weighted by market prices, such shifts should themselves be treated as a statistical "source" of growth.)

16. Even if this is so, it is an open question whether addition of property taxes to capital-land earnings would, on balance, improve the weights in view of the probable overstatement of the capital-land weight in both our estimates that results from counting "pure profit" and all of the corporate income tax in this share.

17. Inclusion of other, smaller reconciliation items between GNP at market prices and GNP at factor cost in property income seems tenable for only one minor subcomponent: corporate contributions to non-profit organizations.

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differential between the increase in capital-land input and labor input to have been far larger than I do. Substitution of my weights for theirs would raise their estimate of output per unit of input much more than 0.08. In the reconciliation I attempt, this extra amount will be reflected in the difference I identify with differences in our measures of changes in inputs, because we are analyzing the growth of different output measures.

The preceding description of the Jorgenson-Griliches methodology pertains to their final estimates, which incorporate the adjustments introduced in moving from their table V to table VI. The weighting structure they initially use—in their tables I through V—is a mixture in that the total capital-land weight includes depreciation but is allocated among components by net earnings alone.

IV. Allocation of the Total Capital-Land Weight Among Components

THE procedures that Jorgenson and Griliches and I adopt to estimate the contribution of capital and land to growth are similar at the most general level.

The total weight of capital and land is first divided among types of capital and land in proportion to the estimated earnings of each type. In my estimates five types are distinguished. One of these, international assets, does not appear in the portion of the economy analyzed by Jorgenson and Griliches. The others are: residential structures and residential land, nonresidential structures and equipment, nonresidential land, and inventories. Jorgenson and Griliches use a different classification. They distinguish among residential structures, nonresidential structures, equipment, residential and nonresidential land, and inventories.

Once the weights are assigned, each component of capital-land is treated as a separate input. An index measuring the quantity of each input must be developed. The weight is then multiplied by the growth rate of the index to arrive at the contribution of each component to growth.[19] (In my case contributions of international assets and, as explained in section V, residential property are calculated by a different procedure that does not require an input index.) The total capital-land contribution is the sum of the contributions of the components. In this section, I consider the weights. Later sections will examine the input indexes.

Because I analyze net product and my total capital-land weight includes only net (after-depreciation) earnings, my total capital-land weight is allocated among types of assets in proportion to their estimated net earnings. Jorgenson and Griliches allocate earnings in two parts. The portion of their capital-land weight corresponding to net (after-depreciation) earnings is allocated by estimates of net earnings, as in my procedure. To net earnings of each type of *depreciable* asset, they add depreciation (replacement in their terminology) in order to obtain gross earnings. This corresponds to their measurement of gross product and inclusion of depreciation in their total capital-land weight. This difference in our weighting procedure is legitimate

Use of asset values to allocate net earnings

The total weight of capital and land (excluding depreciation in the Jorgenson-Griliches estimates) is, as I have indicated, divided among components in proportion to their net earnings. But first the earnings of each component must be estimated, and this requires some assumptions.

The earnings of an enterprise can be measured, but most enterprises use more than one type of capital and land and there is no way to observe directly the earnings of each type. The analyst has no alternative but to assume that the individual enterprise earns the same rate of return on each.[20] Given this assumption, the total net earnings of capital and land in each enterprise can be distributed among different types of assets in proportion to their value to obtain the earnings of each type.

Jorgenson and Griliches introduce a second assumption: that the rate of return is the same in all enterprises. The two assumptions together permit them to allocate the net earnings of capital-land among types of assets by current asset values in the private economy as a whole. Except for a modification for capital gains and taxes, which I shall discuss shortly, this is their procedure.

The second assumption is not required by the nature of the economy.

18. Substitution of their higher estimates of the labor content of proprietors' income for mine, and addition of all the reconciliation items between GNP at factor cost and GNP at market prices to my estimates of capital-land earnings, would lower my labor share of total national income in 1950-62 from 78.6 to 74.1. By my procedures, the difference of 4.5 percentage points would be allocated among nonresidential structures and equipment, nonresidential land, and inventories in proportion to their present weight. (The weight of other capital-land components is independently derived.) Such a shift in weights would lower my estimate of the contribution of labor input by 0.06 percentage points, raise the contribution of capital by 0.14, and hence lower my estimate of the contribution of output per unit of input to the growth rate of national income in the whole economy in 1950-62 by 0.08. The effect on the growth rate of GNP at factor cost per unit of input in the private domestic sector would be the same, for reasons explained in section I.

19. The actual arithmetic of the Jorgenson-Griliches calculation differs from this description, but it is arithmetically equivalent. Suppose, in a year 1, that in current prices total income and output are $100 and earnings of inventories are $5 (equal to 5 percent of the total weight). Suppose that inventory input is measured by its value in 1958 prices, and this value is $100 in year 1 and $110 (10 percent more) in year 2. The more usual procedure would multiply the 10 percent increase in inventory input by its 5 percent weight, and conclude that the increase in inventories had raised output by 0.5 percent. The Jorgenson-Griliches procedure is to divide the $5 of inventory earnings in year 1 by the $100 of constant-price value in year 1 to obtain a "service price" of 5 cents per unit ($1 of value in 1958 prices) of inventories. The 100 units of inventory input in year 1 and the 110 units in year 2 are then multiplied by 5 cents, yielding $5 in year 1 and $5.50 in year 2. The difference of 50 cents is the contribution of the increase in inventories, and is again equal to 0.5 percent of the year-1 value of output.

20. Jorgenson and Griliches and I each assume statistically, subject to some later qualifications about capital gains and taxes, that, if the rate of return is the same for all types of assets, the ratio of net earnings to net value at current prices is also the same. This is not a wholly satisfactory assumption [2, p. 143, and 3, pp. 28, 112-113, 280-294], but it introduces no discrepancy between our results because we both use it.

If data were available, one could allocate earnings separately for each enterprise and add up the results. If it turned out, for example, that enterprises having a high proportion of their assets in inventories had a higher rate of return, on the average, than enterprises having a high proportion of their assets in fixed capital, this procedure would (I believe appropriately) yield a higher weight for inventories and a lower weight for fixed capital than would a summary allocation of total capital-land earnings in the economy as a whole by the value of different types of assets in the economy as a whole. With the statistics available, this procedure cannot be implemented for individual enterprises. But I have found it possible to introduce what I regard as major improvements in the weighting structure by dealing with groups of enterprises.

(1) The earnings of capital and land used in the provision of housing services—called the "services of dwellings" industry in international compilations—were isolated [2, p. 40].[21] They are almost the same as total earnings in this industry since labor earnings are trivial. Since residential capital and residential land are the only types of capital and land used by this industry, and since (by definition) these assets are not used by any other industry, the earnings of residential capital and land can be unambiguously identified. Actual earnings of residential property are smaller than the estimate that would be obtained if total earnings in the economy as a whole were allocated by asset values, and hence my procedure leaves more weight for the remaining assets.[22]

(2) The net flow of property income from abroad, corresponding to the earnings of international assets, was also isolated; however, once my estimates are adjusted to correspond to the scope of the economy they cover, this procedure does not affect the comparison with Jorgenson and Griliches because income from abroad is outside their sector.

(3) The remaining earnings of capital and land—those arising in the domestic nonhousing sector—were divided between farm and nonfarm components. *Within* each sector, the total was distributed among nonresidential structures and equipment, nonresidential land, and inventories, in proportion to their net value. The estimates for the farm and nonfarm sectors were then added to obtain total earnings for each of these three types of assets. Farming has a lower ratio of earnings to assets than the nonfarm nonresidential sector, and a higher proportion of its assets are in land and a lower proportion in structures and equipment. Hence, the separate attention I give to agriculture results in a lower weight for land and a higher weight for nonresidential structures and equipment than would be obtained if the farm-nonfarm division were not made.

My average weights for the 1950–62 period are shown as percentages of total national income and of total nonlabor income in the first two columns of the following table. The next two columns give similar data for the private domestic sector.

The last column gives a percentage breakdown of the total capital-land weight that corresponds *conceptually* to the percentage distribution of the net (after-depreciation) portion of the Jorgenson-Griliches final weights, except for an adjustment for capital gains and taxes that they introduce. (It also corresponds conceptually to their division of the total gross capital-land weight, including depreciation, used in the construction of their table I.)[23]

Their distributions differ from this statistically, however, because they allocated total net capital-land earnings among components by values in the private domestic economy as a whole, without giving separate attention to the "services of dwellings" and agricultural industries.[24] For this reason, they presumably assigned a much higher proportion than I of the total net capital-land weight to residential structures and to residential and nonresidential land, and a lower proportion to nonresidential structures and equipment and (to a lesser extent) inventories.[25] On balance, the weighting structure for net earnings *within* their capital-land aggregate probably yielded a smaller increase in combined capital-land input, and hence tended to produce a *larger* increase in output per unit of input, than my weights would have done. This is chiefly because land, to which they assign more weight, did not increase.

	Whole economy		Private domestic economy	
	Percent of national income	Percent of capital-land earnings*	Percent of national income*	Percent of capital-land earnings*
International assets	0.6	3	.....	.....
Residential structures and land	3.5	16	4.3	17
Nonresidential structures and equipment	11.2	52	13.6	54
Nonresidential land	2.9	14	3.5	14
Inventories	3.2	15	3.9	15
Total capital and land	21.4	100	25.3	100

*Approximate.

21. In most Western European countries, the "services of dwellings" is considered a separate industry, for which the necessary data are published. In the United States, this activity is divided between the "real estate" and "farms" industries and not published separately, but it can be approximated from the details of the national accounts worksheets.

22. My procedures avoid the need to further divide the earnings of residential property between structures and sites. If such a breakdown were desired in order to preserve the Jorgenson-Griliches classification of assets, it could be obtained by allocating earnings *within* the housing sector by asset values.

23. Note, however, that Jorgenson and Griliches classify residential land with other land rather than with dwellings. They also subdivide nonresidential structures and equipment.

24. And possibly also because of differences in data used.

25. In their table I, they presumably also assigned a lower proportion of their total weight than I to structures and equipment and a higher proportion to land and inventories because, to arrive at the current value of structures and equipment, they use the double declining balance formula which yields lower values for such assets than the straight-line formula I adopted. In their final gross earnings weights, this difference is more than offset since depreciation is added back to the capital component to which it pertains.

Capital gains

Anticipated capital gains or losses and taxes on income may bias earnings weights derived in the ways I have described if their presence causes the percentage distribution of asset values to diverge from that of earnings within a sector of the economy where the distributions have been assumed to be the same [3, p. 28]. I believe any such bias in my estimates to be trivial, but must devote extended discussion to the topic because Jorgenson and Griliches assign it a central place in their analysis.

I shall consider capital gains first. Jorgenson and Griliches believe the presence of capital gains or losses affects the validity of the assumption that earnings are distributed like asset values. They state: "Asset prices for different investment goods are not proportional to service prices because of differences in . . . rates of capital gain or loss among capital goods" [1, p. 267]. Their idea is that current asset values are proportional to the sum of earnings and capital gains so that allocation of earnings by asset values assigns too much to assets producing large capital gains and too little to assets producing small capital gains or capital losses. They do not discuss the timespan over which capital gains and losses must be cumulated to secure this proportionality, but I presume it is the discounted value of the anticipated stream of earnings and capital gains that would be supposed pertinent.

The relevance of this idea to the actual data we both use must now be explored. It is necessary, I believe, to distinguish sharply between land and reproducible capital. The current value of land is estimated market value; Jorgenson and Griliches and I rely upon Raymond Goldsmith for data. Land prices may and often do reflect not only current earnings related to current marginal products but also the expectation that marginal products will be higher in the future because of increasing land scarcity (relative to other factors). Land is also an inflation hedge and may reflect the expectation of a rise in the general price level as well. Hence, the ratio of current earnings to value may be lower for land than for capital, and allocation of earnings by value may overweight land and underweight capital.

The case of land has no counterpart within the reproducible capital aggregate. The values Jorgenson and Griliches and I use for capital components are their current replacement costs, estimated by use of price indexes for new equipment, structures, and goods held in inventory. These values are firmly anchored to the present price level and present production costs of capital goods and are not affected by capital gains. (Actually, I doubt that it would matter if the values were true market values, since there is no general reason for these to depart from reproduction costs.) Therefore I see no reason to suppose the allocation of weights among structures, equipment, and inventories is biased by capital gains.

As indicated, land may be overweighted and all the capital components correspondingly underweighted because of capital gains. But if this is true of my weights, the bias must be slight. My weight for dwellings and dwelling sites (including vacant lots, which yield no current income) is completely unaffected because it is based directly on earnings, excluding capital gains, and my procedure does not require a division of this weight between dwellings and their sites. Division of total earnings between farm and nonfarm industries greatly reduces any possible overweighting of private *nonresidential* land. In addition, I used conservative estimates of the value of land (Goldsmith's earlier, rather than later and higher, estimates). Finally, the weight I assigned nonresidential land is so small that it could be reduced even radically with no great effect. If it were cut 40 percent, for example, and this weight reassigned to nonresidential structures, equipment, and inventories, my estimate of the contribution of output per unit of input would fall by only 0.04 percentage points in 1950–62.

If capital gains bias weights obtained from a distribution by asset values, the Jorgenson-Griliches weights, prior to their attempted correction, are subject to larger error than mine because they do not isolate earnings in the "services of dwellings" and agricultural industries in which land is very important.

Jorgenson and Griliches attempt to eliminate the bias that they presume would otherwise enter their weights by introducing a formula that is based on the assumption that, each year, values of types of capital and land are proportional to the sum of the earnings and capital gains derived from them in that year.

The formula can best be understood with the aid of an arithmetic example. Assume for some year the arbitrarily selected data for the private domestic economy shown in the following table. (The table will be used again, and includes some numbers not needed as yet.) For simplicity, I let the data refer to the base year for deflation so that asset values are the same in current and constant prices. The first column gives data based on "true" depreciation (replacement) as estimated by Jorgenson and Griliches; the second, on capital consumption as shown in the national income estimates. Only two types of capital—equipment and inventories—are present, and each has a value of $50,000. (Residential and nonresidential structures are handled like equipment in the formula, and land, like inventories.) During the year, there is a capital gain (realized and unrealized) of $1,500 on the stock of equipment and $500 on inventories. The problem is to divide the total

	Jorgenson-Griliches basis	National accounts basis
Income and product account:		
Sales (equal GNP at market prices)	$60,000	$60,000
Labor earnings	45,000	45,000
Gross capital earnings [a]	15,000	15,000
Depreciation on equipment	7,000	5,000
Interest and profit [a]	8,000	10,000
Interest	1,000	1,000
Profit before tax [a]	7,000	9,000
Corporate income tax [b]	3,333	3,333
Profit less corporate income tax [a]	3,667	5,667
Addenda:		
Value of capital	100,000	----------
Equipment	50,000	----------
Inventories	50,000	----------
Capital gains	2,000	----------
Equipment	1,500	----------
Inventories	500	----------

[a] Includes indirect business taxes and other reconciliation items between factor cost and market price valuation for consistency with the Jorgenson-Griliches classification.
[b] Includes tax on capital gains.

Jorgenson-Griliches gross capital earnings weight of \$15,000 (or 25 percent of the total input weight of \$60,000) between equipment and inventories when the Jorgenson-Griliches estimate of "true" depreciation is accepted.

The usual procedure would assign to equipment the \$7,000 of depreciation on equipment, and divide the \$8,000 of net earnings between equipment and inventories in proportion to their values—in the example, \$4,000 each.[26] The total weight of equipment is then \$11,000 and of inventories \$4,000.

In the absence of a corporation income tax, Jorgenson and Griliches would compute the weight (they call it the "service price") for the \$50,000 value of each of the two assets by the following formula [1, p. 256]:

$$p_k = q_k \left[r + \delta_k - \frac{\dot{q}_k}{q_k} \right]$$

where p_k is the price of the k^{th} capital service, q_k is the price of the k^{th} investment good, r is the rate of return, net of "true" depreciation but inclusive of capital gains, on all capital, δ_k is the "instantaneous rate of replacement of the k^{th} investment good" (i.e., the ratio of depreciation to net value), and $\frac{\dot{q}_k}{q_k}$ is the ratio of the capital gain on the k^{th} investment good to the value of that good.

If there were no capital gains in my example ($\dot{q}_k$ would then be zero for both equipment and inventories), this formula would yield the same weights as the simple procedure: \$11,000 for equipment and \$4,000 for inventories. The price of \$50,000 of equipment would be calculated as

$$\$50{,}000 \left[\frac{8{,}000}{100{,}000} + \frac{7{,}000}{50{,}000} - \frac{0}{50{,}000} \right]$$

or \$11,000.

The price of \$50,000 of inventories would be calculated as

$$\$50{,}000 \left[\frac{8{,}000}{100{,}000} + \frac{0}{50{,}000} - \frac{0}{50{,}000} \right]$$

or \$4,000.

The example actually assumes capital gains of \$2,000, of which \$1,500 is on equipment holdings and \$500 on inventory holdings. When these are introduced, the weights (service prices) shift toward inventories, which have a lower rate of capital gain. The estimated price (earnings) of \$50,000 of equipment becomes

$$\$50{,}000 \left[\frac{8{,}000+2{,}000}{100{,}000} + \frac{7{,}000}{50{,}000} - \frac{1{,}500}{50{,}000} \right]$$

or \$10,500.

The price of \$50,000 of inventories becomes

$$\$50{,}000 \left[\frac{8{,}000+2{,}000}{100{,}000} + \frac{0}{50{,}000} - \frac{500}{50{,}000} \right]$$

or \$4,500.

The assumption of the calculation is that asset values each year are proportional to the sum of net (after-depreciation) earnings and capital gains in that year.[27] Jorgenson and Griliches base their weights (service prices) for each year on such a calculation (or rather a more complicated one to which I shall come shortly) for that year.

I find it impossible to believe that the procedure adopted by Jorgenson and Griliches actually improves the weights. It might be appropriate to apply the Jorgenson-Griliches assumption that values are proportional to the sum of net earnings and capital gains—but only with the use of average capital gains over long periods of time to adjust earlier years—if (1) asset values used in the calculations were independently obtained sales values and (2) substantially different rates of capital gain on different types of capital were forecast by firms and (3) their forecasts were accurate. But the second condition is unlikely and the third so restrictive that I doubt the procedure would be an improvement even if the first condition were met. Actually, the first condition is not met; as already noted, the capital stock values used are not market values but current reproduction costs that are not affected (except very indirectly and irrelevantly) by prospective capital gains. Consequently, the bias that Jorgenson and Griliches seek to eliminate is not present in the original data.[28] Their capital gains adjustment thus introduces a bias in the opposite direction—that is, it overweights capital assets on which capital gains are small.

Even if all three conditions were met, the relevance of an annual calculation would elude me. Since capital gains are highly erratic from year to year, the weights must also change erratically from year to year. It could hardly be argued that market prices of capital goods and land fluctuate annually so as to maintain proportionality between capital values and the sum of earnings and capital gains each year, nor could firms adjust the composition of their real assets annually even if they could foresee the pattern of each year's capital gains and losses. The supposed error in the use of asset values to derive weights for a year could have no relationship at all to the size of capital gains in that year.

Tax on corporate profits

I turn now from capital gains to taxes on income. Jorgenson and Griliches consider only the tax on corporate profits. It is sometimes argued that the presence of this tax leads to allocation of resources in such a way as to cause the after-tax rate of return in the corporate sector to be the same as, and hence the before-tax rate of return higher than, that in the noncorporate sector.

Because earnings from all types of capital and land used by corporations are taxed alike, it is easy to avoid any bias from this source in the distribution of capital-land earnings (which include this tax) among types of assets if asset values are available separately for corporations. One need only allocate earnings of capital and land in the taxed corporate sector in proportion to asset values in corporations, to allocate earnings in the untaxed noncorporate sector in proportion to noncorporate asset values, and then to add the two

26. I follow here the Jorgenson-Griliches procedure of counting indirect taxes, etc., as part of the net earnings component.

27. The calculation implies net earnings of \$3,500 and capital gain of \$1,500 for equipment, and net earnings of \$4,500 and capital gain of \$500 for inventories.

28. Except perhaps for the division of the weight between land, on the one hand, and the four capital components as a group, on the other.

distributions to secure the final earnings estimates for use as weights. This procedure avoids any bias from the tax whether the tax diverts resources from the corporate to the noncorporate sector or does not.

My estimates do treat separately two sectors that are overwhelmingly noncorporate: housing and agriculture. However, the combined earnings of corporate and noncorporate firms within the nonfarm nonhousing sector were allocated by their combined asset values. This introduces an error into my weights for nonresidential structures and equipment, inventories, and nonresidential land if both (1) the rate of return after tax (rather than before tax) was the same for corporate and noncorporate firms, and (2) the percentage distribution of assets among the three types was different in corporate and noncorporate firms. The first condition would mean that before-tax earnings per dollar of value of each type of capital and land are higher in corporations than in noncorporate firms. If this is so, and if the second condition is also met, failure to allocate capital-land earnings of corporate and noncorporate firms (within the nonfarm nonhousing sector) separately would yield too large an estimate for earnings of types of assets used most by noncorporate firms and too small an estimate for types used most by corporations. However, the distribution of assets in noncorporate nonfarm firms could scarcely differ enough from that in nonfarm corporations to introduce an error of appreciable size.

Because Jorgenson and Griliches make a single allocation for the whole private domestic economy, without isolating housing and agriculture, the potential bias in their estimates is much larger and extends to residential as well as nonresidential capital and land. The direct way for them to remove the potential bias would be to make separate allocations of earnings in corporate and noncorporate sectors. An indirect way, having no advantage because it requires the same information, would be to increase the weight attached to corporate assets by (1) raising the value of corporate holdings of each type of asset by the ratio of after-tax earnings to before-tax earnings in corporations; (2) adding the resulting adjusted value of corporate holdings to the unadjusted value of noncorporate holdings of each type of asset; and (3) allocating combined corporate and noncorporate before-tax capital-land earnings among types of capital and land in proportion to the adjusted asset values so obtained. I surmise that Jorgenson and Griliches may have had this in mind when they introduced their formula for the determination of service prices in the presence of a direct tax on income.

This formula, which is used in their actual calculations in place of the simpler formula already discussed, is quite complex because it tries to deal simultaneously with capital gains and the corporate income tax, including the effects of differential taxation of capital gains. I believe the formula is intended to allocate earnings among types of capital and land on the assumption that asset values each year are proportional to the sum of net (after depreciation) earnings and capital gains in that year when earnings and capital gains from each type of asset are each measured after deduction of the corporate income tax applicable to them.

The formula, which I shall now describe, does not actually do this. In fact, it does nothing at all to remove the bias, just discussed, that allocative effects of the corporate income tax may be presumed to introduce. The reason is that Jorgenson and Griliches apply the *same* ratio of before-tax earnings to after-tax earnings (the average ratio for the whole private economy) to both corporate and noncorporate assets instead of using the corporate ratio for corporate assets and a ratio of one for noncorporate assets.

Introduction of new terms does not improve the results obtained by the simpler no-tax formula already described but instead compounds the errors. In particular, it accentuates the erroneous shift of the weights from capital-land components on which capital gain is high to those on which capital gain is small. In addition, it shifts weight from depreciable assets to land and inventories if (as is the case) "true" depreciation as measured by Jorgenson and Griliches exceeds capital consumption allowances as measured in the national accounts (which they use as a proxy for depreciation allowable for tax purposes). I presume their purpose in doing this is to allow for supposed effects of taxing depreciable assets on amounts that represent recovery of capital rather than true earnings, but defects in their formula and measurements make the amounts shifted haphazard.

The formula [1, p. 267, formula 11] is:

$$p_k = q_k\left[\frac{1-uv}{1-u}r + \frac{1-uw}{1-u}\delta_k - \frac{1-ux}{1-u}\frac{\dot{q}_k}{q_k}\right].$$

The definitions of the terms [as given in 1, pp. 256, 267, and 277–279 and in correspondence from the authors] and their values for equipment and for inventories in my example above are as follows:

p_k is the price of the k^{th} capital service. In using the example, I let it refer for convenience to the price of the service of \$50,000 worth of equipment, and of \$50,000 worth of inventories.

q_k is the price of the k^{th} investment good. In the example, it is \$50,000 for equipment and \$50,000 for inventories.

u is the ratio of corporate profits tax liability to profits before taxes in the private domestic sector of the economy.

Corporate profits tax liability is taken from the national accounts. It includes tax liability incurred because of inventory profits and other capital gains.

"Profits before taxes" in the private domestic sector are measured as property income (Jorgenson-Griliches definition) less capital consumption allowances and private domestic net interest, both taken from the national accounts. Profits before taxes are therefore equal to the sum of "corporate profits and inventory valuation adjustment" in the domestic sector, the proportion of "proprietors' income" not allocated to labor, the "rental income of persons," "indirect business tax and nontax liability," "business transfer payments," and "statistical discrepancy," minus "subsidies less current surplus of government enterprises." [29]

If the reason that Jorgenson and Griliches count indirect taxes as capital-land earnings is a belief that their shortrun incidence is on this share, one would also expect indirect taxes to be counted as taxes on these earnings. This is not done; indirect taxes are not counted as taxes on income but as part of income after tax.

This variable is the same for each type of asset, regardless of its distribution between the corporate and noncorporate sectors. In the example,

$$u=\frac{3,333}{9,000}=.3704.$$

r is the ratio of (a) total income from property less profits tax liability less the current value of replacement plus the current value of capital gain to (b) the current value of capital stock. It is the same for all types of capital and land. In the example,

$$r=\frac{15,000-3,333-7,000+2,000}{100,000}=.06667.$$

v is the ratio of private domestic net interest to the after-tax rate of return, r, multiplied by the current value of the capital stock. It is the same for all types of capital and land. In the example,

$$v=\frac{1,000}{.06667\times 100,000}=.15.$$

w is the proportion of "true" replacement (depreciation) that is allowable for tax purposes. Jorgenson and Griliches obtain this proportion as the ratio of capital consumption allowances, as measured in the national accounts, to their estimates of depreciation (replacement). They use the same ratio for all types of depreciable assets (residential structures, nonresidential structures, and equipment). For equipment in the example,

$$w=\frac{5,000}{7,000}=.7143.$$

No value is needed for inventories (or land).

δ_k is the rate of replacement (depreciation) of the k^{th} investment good. For equipment in the example,

$$\delta_k=\frac{7,000}{50,000}=.14.$$

No value is needed for inventories.

x is defined as the proportion of capital gains included in income for tax purposes. However, Jorgenson and Griliches inform me that, in their calculations, x actually was assumed to be zero for all types of assets.[30]

$\frac{\dot{q}_k}{q_k}$ is the rate of capital gain on the k^{th} investment good. I defer a description of the derivation of $\dot{q}_k$. In the example, the ratio is

$$\frac{1,500}{50,000}=.03 \text{ for equipment,}$$

and

$$\frac{500}{50,000}=.01 \text{ for inventories.}$$

When the values derived from the example are inserted, weights of $10,794 for equipment and $4,206 for inventories are obtained. For equipment p_k equals:

$$\$50,000\left[\frac{1-(.3704\times.15)}{1-.3704}\times.06667+\frac{1-(.3704\times.7143)}{1-.3704}\times.14-\frac{1-(.3704\times 0)}{1-.3704}\times.03\right]=\$10,794.$$

For inventories, p_k equals:

$$\$50,000\left[\frac{1-(.3704\times.15)}{1-.3704}\times.06667+.00-\frac{1-(.3704\times 0)}{1-.3704}\times.01\right]=\$4,206.$$

Effects of the formula

It is informative to recapitulate results from the example, and insert the results of one additional calculation. When no account was taken of capital gains or taxes, weights of $11,000 for equipment and $4,000 for inventories were obtained. Use of the no-tax formula to allow for capital gains shifted the weights to $10,500 and $4,500. If tax depreciation had been the same as true depreciation in the example, substitution of the formula with taxes present would have further shifted the weights to $10,046 and $4,954, this change reflecting the Jorgenson-Griliches assumption that capital gains are tax free.[31] With allowance, in addition, for taxation of part of "true" depreciation on equipment, the weight of equipment is raised to $10,794 and that of inventories reduced to $4,206. The particular numbers reflect only the figures assumed in the example, of course, but the direction of the changes at each

29. As originally printed, the Jorgenson-Griliches article stated that "the variable u, the rate of direct taxation, is the ratio of profits tax liability to profits before taxes for the corporate sector. These data are from the U.S. national accounts" [1, p. 277]. This definition, though logical if u were to be used only for corporate assets, would make the equation as it stands wholly inconsistent.

30. In their article this is not really clear. They write only that "the proportion of capital gains included in income is zero by the conventions of the U.S. national accounts" [1, p. 267]. This must be interpreted to mean that "the variable x, the proportion of capital gains included in income for tax purposes (but not the value of capital gains as they appear elsewhere in the formula) is zero." The two statements are unrelated, and while the first is true, the second is not. Some capital gains (the inventory valuation adjustment in particular) are fully, and others partly, taxed. Jorgenson and Griliches include these taxes in the numerator of u, which has the effect of charging them to earnings instead of to capital gains. With x equal to zero, $-ux$ in the numerator of the last term of the formula could be omitted without changing the results.

31. This calculation uses only the column in the example headed "Jorgenson-Griliches." The values of the variables are the same as those just given except that u is .4701 instead of .3704, and w (for equipment) is 1 instead of .7143.

step helps to explain just what the formula does to the weights. I have already pointed out the main consequences.

The Jorgenson-Griliches formula may have theoretical interest.[32] But as they have applied it, it is hardly to be taken seriously as a tool for statistical analysis. The alterations in weights, away from assets with large capital gains, that would be introduced by their simple "tax-absent" formula are untenable. If they were tenable, the additional changes introduced by their "tax-present" formula would not be. The only bias potentially introduced by the corporate income tax (except by differential taxation of earnings and capital gains) is not affected. The overall corporate tax rate, u, as measured, is meaningless. It also is obviously wrong to assume that this tax bears as heavily upon dwellings and land as upon other assets. How indirect taxes can be counted as part of before-tax capital-land earnings but not as a tax on these earnings defies my understanding. Capital gains are not actually taxed at zero, as is assumed; they are taxed at a wide range of effective rates, ranging up to full taxation of the nonfarm inventory valuation adjustment. The fraction of depreciation (replacement) as measured by Jorgenson and Griliches that is taxable is not the same for all types of depreciable assets, as is assumed; the ratio of reproduction cost to original cost varies greatly between long-lived structures and short-lived equipment, and the proportions of these assets on which fast depreciation is allowed also varies greatly in the later years of their period.[33] Furthermore, much of the depreciation in the national accounts (particularly that on most dwellings) has no tax relevance at all (and farm depreciation is already on a replacement-cost basis). But these objections are, of course, largely superfluous if I am correct in asserting that the capital gains adjustment is itself a mistake.

Estimates of capital gains

The estimates of capital gains used by Jorgenson and Griliches that underlie the whole analysis are themselves subject to considerable criticism. The capital gain on any type of asset in a year is properly the difference between (a) the change in the value of holdings of the asset from the beginning to the end of the year, and (b) the value of the change in the quantity of the asset, measured in current prices. This figure can be approximated within an acceptable error by multiplying the value of the asset at the beginning of the year by the percentage change during the year in a price index for the stock of the asset.

Jorgenson and Griliches inform me that they used the former of these methods to secure capital gains on land, utilizing data from Raymond W. Goldsmith. For the capital items, however, they use neither of these measures. They write: "The capital gain for each asset is the product of the rate of growth of the corresponding *investment* deflator and the value of the asset in constant prices of 1958" [1, p. 279, italics added]. This differs from proper procedure in two respects. First, they measure changes in prices from the average of one year to the average of the next, instead of from the beginning to the end of the year. This is important for their annual series, but probably washes out over a period of years. Second, and more important, they use the implicit deflator for investment instead of the implicit deflator for the capital stock. This procedure yields an accurate approximation of the capital gain only if the two deflators are the same. They are the same if, but only if, the composition of the stock of an asset is the same as the composition of investment in it during each of the years compared—gross investment in the case of depreciable assets, net investment in the case of inventories. Only in this case are the weights appropriate for a capital stock price index the same as those that underlie the investment price index.

In the national accounts framework, this condition is met only for residential structures, which are treated as a single commodity both in deflation of investment and in building up a capital stock series. It is not met for nonresidential structures or for producers' durables, for each of which deflation is performed in considerable detail.[34] It is wildly not met for inventories; the composition of inventory change is usually very different from that of the stock of inventories. Moreover, the composition of inventory change varies greatly from year to year. As a consequence of this (together with the fact that, on a 1958 base, the levels of price indexes for different inventory components diverge greatly as one moves away from 1958), the implicit deflator for the change in inventories properly moves very erratically, especially in years far removed from 1958, even though the deflator for the stock of inventories moves smoothly. Jorgenson and Griliches note and dislike these wild movements. But instead of correcting their method to use the deflator for the stock of inventories instead of inventory change, they arbitrarily alter the deflator for inventory change by substituting the consumption deflator.

Depreciation

When an investment yielding a positive gross return is made, gross output is increased, depreciation is increased, and net output is increased by the difference between the two, which is the net product of the investment. If one were interested in analyzing the growth of both gross and net product, he could proceed in any of three ways. (1) He could analyze the growth of net product using net earnings weights (as I did in *Why Growth Rates Differ*), and add constant-price depreciation to output and to the contribution of capital in order to analyze gross product (as I did in section I of this paper). When I apply this method to the private domestic sector covered by Jorgenson and Griliches, my estimates yield the following results:

	Growth rate of output	Contribution of inputs	Contribution of output per unit of input
Net product	3.23	1.73	1.51
Gross product	3.55	1.97	1.58

32. However, if the formula is viewed as a theoretical construct rather than a description of their procedures, u, v, w, and z should all carry the subscript k since they differ for each asset type.

33. Tax depreciation differs from the Jorgenson-Griliches estimate of true depreciation chiefly because original cost is not the same as reproduction cost and because double declining balance depreciation is not allowed or, if allowed, is not used by taxpayers because they do not think it to be to their advantage.

34. The fact that Jorgenson and Griliches treat each of these as a single commodity, with a single service life, in constructing capital stock series does not suffice to remove the objection.

(2) He could analyze the growth of gross product using gross earnings weights (as Jorgenson and Griliches do), and subtract constant-price depreciation from output and from the contribution of capital in order to analyze net product. (3) He could analyze the growth of net product using net earnings weights and the growth of gross product using gross earnings weights. The three procedures are exactly equivalent only in special circumstances, but their results are not likely, in practice, to diverge very much. To explore the considerations involved in the choice would take me far afield, and I content myself with the assertion that, to measure net product, it is better to use net product weights than to follow the second alternative.

Jorgenson and Griliches [1, p. 257] criticize John W. Kendrick for not using service prices as his weights. They are wrong. Kendrick analyzed growth of net product and appropriately used net earnings weights. To include depreciation in the weights in an analysis of the growth of net product, as Jorgenson and Griliches insist he should do, would be a plain error that would lead to overstatement of the contribution of capital to growth.[35] That the other aspect of their service prices—their capital gains and tax adjustment—would have improved his estimates is just not credible on the basis of my preceding discussion.

Effect of differences in weights

When Jorgenson and Griliches adjust their initial estimates to use what they call "prices of capital services" in their calculations, they raise their 1950–62 growth rate of total input, and lower that of output per unit of input, by 0.35 percentage points [computed from 1, tables V and VI]. This number combines the effects of two changes from their initial estimates. First, Jorgenson and Griliches remove an error present in their initial weights. Whereas they initially allocate the depreciation component of their gross capital-land earnings weight like net earnings, they now allocate it correctly by depreciation. Second, they introduce the adjustment for capital gains and corporate income tax that I have described. The portion of the 0.35 percentage points that results from the reallocation of depreciation does not represent a discrepancy between their estimates and mine of the contribution of output per unit of input to GNP growth in the private domestic sector. I cannot isolate this portion but it is clearly substantial and, like the combined adjustment, positive. The portion that results from the adjustment for capital gains and taxes does cause a discrepancy, but I cannot isolate the amount nor even be sure whether it is positive or negative.[36] Neither can I calculate the discrepancy between our results (not necessarily included in the 0.35) that is introduced by my according separate treatment to housing and agriculture. Hence, I cannot measure the difference in our output per unit of input series that resulted from the difference in our allocation of the total capital-land weight among components, and this introduces a gap into the reconciliation table I provide in section IX.[37]

Consideration of the bearing of the Jorgenson-Griliches discussion of service prices upon my own estimates suggests only one qualification of my procedures. This is the possibility, already examined, that I may slightly bias my results by overweighting nonresidential land.

V. The Measurement of Capital-Land Inputs (Excluding the "Utilization" Adjustment)

I turn now to input series for the various types of capital and land. This section compares my estimates with those of Jorgenson and Griliches after their adjustment for what they call "errors" in investment goods prices, but not for changes in "utilization." Their "utilization" adjustment will be discussed separately in section VII.

Nonresidential land

Jorgenson and Griliches and I each estimate the input of nonresidential land to have been constant over the period.[38] Its contribution to growth is therefore zero in both series.[39]

Inventories

To measure inventory input, I use the OBE series for the value of farm and nonfarm inventories in 1958 prices; this is the series that is consistent with the annual changes published in the national accounts. The growth rate of this series times the inventory share of national income equals the contribution of inventories to growth.

Jorgenson and Griliches initially use a conceptually similar, but statistically different, series obtained by starting with a base-year value and cumulating annual changes published in the national accounts. They then introduce a certainly erroneous change in the price deflator; they substitute for the inventory deflator the deflator for personal consumption expenditures. This error is apparently a byproduct of their faulty procedure for measuring capital

35. Unless the second alternative listed above were to be adopted, which Jorgenson and Griliches do not suggest.

There have been some studies of gross product that have included depreciation in the weight of capital and land as a whole but have allocated it among components by value of the stock. The Jorgenson-Griliches criticism of this procedure (which corresponds to theirs in construction of their table I) is correct.

36. The percentage division of the Jorgenson-Griliches gross capital-land earnings weight between net earnings and depreciation also affects the results. It may or may not differ appreciably from mine. Their depreciation is presumably larger because they use the double declining balance instead of the straight-line formula. But their net earnings are also larger because they include indirect taxes.

37. The combined effect of this and certain other differences is estimated in section IX to be 0.33 percentage points.

38. Their estimates combine residential with nonresidential land. Perhaps they would assume some slight decrease in nonresidential land and an increase in residential land if they were to make the distinction.

39. Because of differences in the weight assigned to this nongrowing factor, already discussed, this does not mean that land does not affect our results.

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gains, which I have already discussed.

Growth rates of the stock of inventories from 1950 to 1962 are 3.00 for my series [2, p. 190], 4.06 for their initial series, and 4.14 for their series after the price substitution (both computed from 1950 and 1962 values in 1958 prices provided by Jorgenson and Griliches). The initial Jorgenson-Griliches inventory series increases by about the same *absolute* number of 1958 dollars as mine. Its much larger *percentage* change and growth rate reflect a much lower figure for the base-year value of the stock; their series for total inventories runs at a bit lower level than the OBE series for nonfarm inventories alone. The data they use for level and change are evidently inconsistent.

The difference of 1.14 points between their final inventory growth rate and mine accounts for 0.04 percentage points of the difference between our estimates of output per unit of input growth, based on my share weights; the amount based on their share weights would probably be about the same. Of the divergence, 0.03 is due to the low level of their inventory series; this is raised to 0.04 by their price adjustment.

Nonresidential structures and equipment: Denison series

One's choice of a capital stock series to measure input of nonresidential structures and equipment necessarily depends on his judgment as to whether or not the ability of a capital good to contribute to production declines during its actual service life because it performs less well, requires more maintenance, or is installed in a less optimal use than it was initially as a result of demand shifts and the like; and, if it does decline, by how much and in what time pattern. Gross stock (the value of the stock without deduction for accumulated depreciation) provides an appropriate measure if there is no decline. Use of a net stock series is always inappropriate on theoretical grounds; net value drops as the length of the remaining service life declines, and this has no relevance to ability to contribute to production currently. In *Why Growth Rates Differ*, I assumed that the ability of capital goods to contribute to production typically does decline during their service lives but not very much. I suggested [2, pp. 140–141] that if one weighted the growth rate of gross stock about 3, and that of net stock based on straight-line depreciation about 1, he would obtain a series that might reasonably approximate the decline in the ability of capital goods to contribute to production as they grow older. To give some weight to net stock in this way is merely a convenient method of introducing a declining pattern.

In my actual estimates, I gave *equal* weight to gross stock, based on Bulletin F lives, and to net stock, based on Bulletin F lives and straight-line depreciation. (For the 1950–62 period, but not the subperiods, estimates of the contribution of capital to growth with the capital stock data I had were actually the same whether gross stock or net stock was used, so that the weights actually did not matter for the whole period.) I did so partly because I feared the gross stock series then available to me was unduly sensitive to possible errors in estimated service lives as a result of its construction with but little detail and without a distribution of retirements, and I wished to reduce this sensitivity; and partly because of the needs of international comparisons [2, pp. 140–141].

My estimates were made before the latest OBE capital stock study was completed. Before I continue this section, the change that use of the new OBE data would introduce into my estimates needs examination. Had the OBE study been completed, I would have used OBE capital stock series based on Bulletin F lives, on use of the Winfrey distribution for retirements, and on use of the OBE "price deflation II."

Growth rates of the stock of nonresidential structures and equipment from 1950 to 1962 computed from five measures, and my estimates of the contribution of structures and equipment to the growth rate based on each, are as follows: [40]

Nonresidential structures and equipment capital stock series	Growth rate (percent)	Contribution to growth rate of national income (percentage points)
Average of gross and net stock series, equal weights:		
1. Used in *Why Growth Rates Differ*	3.74	0.40
2. OBE revised—Deflation I	3.24	.37
3. OBE revised—Deflation II	3.51	.40
Average of gross stock (weighted 3) and net stock (weighted 1):		
4. OBE revised—Deflation II	3.40	.39

Row 1 shows the estimates I actually used. Row 2 shows that the incorporation of revised OBE data, based on Bulletin F lives, straight line depreciation, and the Winfrey distribution, but retaining the same deflators (OBE Deflation I) as the estimates I actually used, would lower my estimate of the contribution of capital to growth by 0.06 percentage points. The change is due mainly to the use of much more detail in the calculation of stocks. Row 3 shows that substitution of OBE's series based on their Deflation II for nonresidential structures would yield a contribution of capital 0.03 percentage points higher than does use of their Deflation I series. (I shall comment on the difference shortly.) After this substitution, the contribution of nonresidential structures and equipment based on revised data remains 0.03 points lower than the estimate I actually used.

Given estimates incorporating the Winfrey distribution and the use of considerable commodity detail, and in the absence of international comparisons, I would weight gross stock about three and net stock (based on straight line depreciation) one, instead of assigning equal weights. This would yield a contribution of 0.39 points (row 4) and would lower the estimates I actually used for the contribution of capital by 0.04. My estimate for the contribution of output per unit of input is thus 0.04 points too low by reference to the estimate I would now secure by use of the data presently available.

40. The revised OBE data were provided by letter on December 19, 1967. My average 1950–62 weight for nonresidential structures and equipment is 11.2 percent of total input.

Nonresidential structures and equipment: Jorgenson-Griliches series

Jorgenson and Griliches treat nonresidential structures and producers' durables as separate inputs in their estimates. For each, they use the double declining balance formula to obtain a capital stock series. No detail is used for either calculation.

Capital stock series obtained by the double declining balance formula have always heretofore been described as "net stock" series. Estimates of the value of net stock obtained by this formula assume that net value declines rapidly—much more rapidly than the straight line formula assumes. Justification of so rapid a decline in net value has relied on the argument that obsolescence is rapid; this justification seems to require that obsolescence not only shortens service lives (this is reflected in all capital stock series) but also *greatly* accelerates the loss of value during the shortened service life.

Although their method is the same, Jorgenson and Griliches sometimes appear to regard the series they obtain by the double declining balance formula not as a net stock series but as a gross stock series. Thus, in describing the derivation of a capital series, they state [1, p. 255]: "The quantity of new investment goods reduced by the quantity of old investment goods *replaced* must be added to accumulated stocks." And, again: "We assume that the proportion of an investment *replaced* in a given interval of time declines exponentially over time." [Both italics mine.] And they usually (though not on page 277) refer to the value eliminated from the stock each year as "replacement" rather than as depreciation. *If* they mean "replacement" to be construed as equal to discards, they are indeed trying to construct a gross stock series. But if this *is* their intent, their method is certainly odd. I do not know what evidence they would muster to support the assumption (which is also applied, even more improbably, to dwellings) that discards decline exponentially (i.e., are greatest in the first year after purchase or installation and thereafter decline each year). But even if it were true that discards decline exponentially, their exponents (because they use *double* declining balance) apparently are about twice too big to retain the (Bulletin F) average service lives that they initially accept and from which they begin the calculation [1, p. 277]; that is, they greatly cut their own average service lives. Starting with a 15.1-year average service life for equipment, for example, they estimate half the stock has vanished after 5 years, and seven-eighths after 15 years.

Whatever the intent, changing the name does not change the data, and I shall regard the series constructed by Jorgenson and Griliches as measuring what such series have always been regarded as measuring—the net stock based on the double declining balance formula—and what they call "replacement" as an estimate of depreciation. A series based on this formula makes the ability of an individual capital good to contribute to current production drop much faster than seems to me at all plausible. Whatever can be said to justify *its* use in measuring net value has no relevance to measurement of changes in ability to contribute to current production.

I have puzzled over the Jorgenson-Griliches discussion of why they use their formula [1, p. 255] but have been unable to discern its relevance to the choice of a capital stock series to measure changes in capital input.[41]

It may be necessary to note here that the choice of a particular formula to measure capital depreciation (or "replacement") in the process of computing income share weights, including the net capital values used to allocate total net capital-land earnings among components, in no way dictates that the same formula should be used to construct the capital stock series that is used to indicate changes in capital input over time. Different series not only can be used for the two purposes but, conceptually, must be. For weighting, value must decline as remaining service life diminishes whereas a measure of current services must not do so. Thus, it is entirely consistent to use net stock values to determine weights, and whatever series seems most suitable (including, in particular, gross stock) to measure changes in capital input (or services) over time. Jorgenson and Griliches themselves accept this view when they adjust their capital services for changes in utilization (section VII below) without changing their depreciation.

I wish to stress that the choice of depreciation or replacement formula appropriate for measurement of changes in capital input has nothing to do with "vintages," that is, with the way one wishes to treat quality differences in capital goods that do not reflect a difference in costs and that result in "unmeasured" quality change (or "embodied" technical progress) as time goes on. Use of a fast depreciation formula is not a method of making an allowance for unmeasured quality change. This can be readily seen from the fact that, with any continuous rate of quality improvement in capital goods, net capital stock based on double declining balance depreciation can rise either more or less than gross stock or net stock based on straight line depreciation. From 1950 to 1962, for example, data from the OBE capital stock study show identical percentage changes for net stock when straight line depreciation is used and when the double declining balance method is used.[42]

Jorgenson and Griliches employ series they themselves derive by use of the double declining balance formula. They assign a single service life to all nonresidential structures and to all producers' durables, whereas OBE assigns different lives to each of a large number of components. The growth rate of their value of nonresidential structures and equipment (from the beginning of 1950 to the beginning of 1962) is 0.17 higher than that of the corresponding OBE series. Even so,

41. The Jorgenson-Griliches discussion seems to visualize steady growth of replacement investment, and their rationalization seems to require, in addition, steady growth of new investment. But if gross capital investment grew at a steady rate (and service lives were not changed over time), it would make little or no difference whether an index of gross stock (in the usual sense of the term) or of net stock computed by any of the usual formulas were used to measure capital input. It is only because investment has been irregular—particularly because of depression and war—that the problem of selection has any importance.

42. This is the case whether "constant cost I" or "constant cost II" estimates are compared. Changes are computed from the average of the beginning and end of 1960 to the similar figure for 1962.

in the period examined, their series is not radically different from other measures. The 1950–62 growth rates of the capital stock series they initially obtained (prior to their price substitution) and used in constructing their table I, are 4.11 for equipment, 3.42 for nonresidential structures, and 3.72 for nonresidential structures and equipment combined (computed from data for the value of the stock in 1958 prices provided by Jorgenson and Griliches).

However, in moving from their table II to table IV, Jorgenson and Griliches greatly accelerate the rise in the growth of the equipment stock by deflating past gross investment in producers' durables by the price deflator for consumers' durables instead of that for producers' durables. This substitution raises the 1950–62 growth rate of their equipment stock alone by 1.49 points, to 5.60, and the growth rate of nonresidential structures and equipment combined by 0.62 points, to 4.34 (computed from capital stock data provided by Jorgenson and Griliches).

To justify the substitution, Jorgenson and Griliches state that, for items that appear in both the BLS consumers' price index and the BLS wholesale price index, the retail and wholesale series diverge by roughly the same amount as the composite indexes. They further state that the consumers' price index is better because more money is spent on it.

It is desirable to deflate common components of consumers' expenditures for durable goods and producers' purchases of durable goods by the same deflator, the best available—at least when they are sold by the same outlets on similar terms. But automobiles are the only important common component (as well as the only component of the consumer and wholesale price indexes that is mentioned by Jorgenson and Griliches).[43] And OBE already uses the same (consumers') price series to deflate consumer and business purchases of automobiles. The sharp divergence between the implicit deflators for all consumers' durables and all producers' durables is ascribable to commodities *not* common to the two series. Production processes for the two sets of goods are very different. Consumers' durables, which had the smallest price rise of any sizable product group, are dominated by mass-produced, standardized products. Their exceptional price behavior was due to radio and television receivers, "kitchen and other household appliances," and automobile "tires, tubes, accessories, and parts." Producers' durables, in contrast, are dominated by items produced in small volume, including a large element of individualized, built-to-order items most akin to custom services. I do not see how any inference about changes in prices of producers' durables can be drawn from prices of consumers' durables, or that the latter provide a more relevant comparison with the former than any other prices.

The OBE deflator for producers' durables is, to be sure, subject to substantial error in either direction because the data entering it are incomplete and their reliability low—mainly because so many components are *not* standardized. But there is no a priori presumption that the series is biased upward by reference to the usual price index criteria. I regard this substitution as unwarranted.

It must be stressed that this price substitution cannot be rationalized as an attempt to allow for quality change not involving a difference in costs at a common date ("unmeasured" quality change). Neither the CPI nor the WPI makes any such allowance (nor do any of the GNP deflators).[44]

In contrast to producers' durables, there is a presumption that the deflator for the nonresidential structures portion of GNP is biased upward by reference to usual price index criteria. This is because most components are based on prices of construction materials and labor, rather than on output prices, and hence do not allow for changes in output per man-hour in on-site construction work. This bias has long been recognized, but its size has been hard to appraise.

For use in its capital stock study, OBE developed an alternative nonresidential construction price series that attempts to eliminate this bias, and used it as an alternative to the GNP nonresidential construction price deflator to derive its Deflation II capital stock estimates that I have already mentioned. These estimates differ from OBE's Deflation I estimates only because of the use of a different construction deflator. Jorgenson and Griliches make the same substitution in moving from their table II to table IV. This raises the 1950–62 growth rate of their nonresidential structures series by 0.50 percentage points, from 3.42 to 3.92, and the growth rate of nonresidential structures and equipment combined by 0.28 points, from 3.72 to 4.00 (computed from data provided by Jorgenson and Griliches).[45] The effect on the combined series is almost identical to that (0.27 points) introduced when the similar substitution was made between lines 2 and 3 of the text table above, and the effect upon the growth rate of *total* input when my weights are used is also the same, 0.03 percentage points.[46]

The 4.00 growth rate of the stock of nonresidential structures and equipment obtained by Jorgenson and Griliches when their construction price substitution but not their equipment price substitution is introduced may be compared with the 3.40 growth rate I obtain by use of the revised OBE data with use of Deflation II (text table above). The 0.60 difference reflects both a difference in choice of capital stock series and OBE's greater use of commodity detail. Based on my weights, it accounts for 0.07 percentage points of the difference between us in output per unit of input.

Residential structures and land

My methodology does not require an input series for residential structures

43. Some types of office furniture might be regarded as having a household counterpart, and there are items of trivial importance.

44. In my view, there is no way to do so. But this is a controversial matter that need not be discussed here.

45. With both the equipment and construction price substitutions, the 1950–62 growth rate of the Jorgenson-Griliches series for nonresidential structures and equipment is 4.65.

46. Robert J. Gordon has also attempted to construct a series for deflation of nonresidential construction from which the bias has been eliminated. Data he has generously provided me show that substitution of his series for the OBE nonresidential construction deflator would raise the growth rate of a series for the stock of nonresidential structures and equipment (specifically, the gross stock based on Bulletin F lives) by 0.60 percentage points. A change of this size would raise the growth rate of a total input series, based on my weights, by 0.05 percentage points as against the 0.03 indicated by the OBE Deflation II series.

and land. Instead, I isolate the amounts of national income, measured in constant prices, that originated in the "services of dwellings" industry in the same way as the current dollar figures were obtained in deriving share weights. The same procedure can be followed for GNP at factor cost. I find [2, pp. 123–126, 413] that the increase in the stock of dwellings and residential land contributed 0.25 percentage points to the growth rate of national income and 0.32 points to the growth rate of GNP at factor cost from 1950 to 1962.[47] This method of direct measurement, which I first used in [2], is, in my opinion, an important advance in growth analysis. It provides a measure for the contribution of this very large part of the capital-land stock to the growth of output as actually measured that is entirely accurate, except for some slight statistical difficulty in the United States in disentangling the details of the national product estimates. An incidental advantage, it may be noted, is that the figure for the contribution to GNP makes no use of, and consequently cannot be affected by, errors in the price index for residential construction.

Jorgenson and Griliches measure the contribution of residential structures as the growth rate of the dwellings stock times the weight assigned to dwellings—the procedure I used in an earlier study [3]. However, instead of using a gross stock series to measure changes in the services of dwellings, as I did then, they use net stock calculated by the double declining balance formula. It seems to me impossible to suppose that this pattern remotely resembles that of the flow of services of dwellings during their service life. The 1950–62 growth rate of the dwellings stock computed by this formula, as they initially estimate it for use in their table I, is 4.53 (computed from data provided by Jorgenson and Griliches).

The deflator for residential construction may be presumed to have an upward bias for the same reason as the deflator for nonresidential construction. Jorgenson and Griliches attempt to allow for this by deflating residential construction expenditures by the OBE Deflation II series for nonresidential construction in place of the residential construction deflator. This raises the 1950–62 growth rate of their dwellings stock by 0.39 points, from 4.53 to 4.92.[48]

Residential land is combined with other land in the Jorgenson-Griliches procedure. As already indicated, their combined growth rate (and contribution to growth) is zero.

If I had used the Jorgenson-Griliches growth rate for the net stock of dwellings, and multiplied it by *my* share weights, I would have obtained a much lower figure than I did for the contribution of dwellings to growth of total national income: probably around 0.13 percentage points instead of 0.25.[49] My output per unit of input series would then have been raised by about 0.12 points. I am not, unfortunately, able to quantify the effect upon *their* estimates of the difference between us in the measurement of the contribution of housing.

Summary comment

The Jorgenson-Griliches estimates of the contribution of capital and land to GNP growth differ from mine because of (1) differences in weights; (2) differences in the initial method of measuring capital and land inputs, including the difference in method of estimating the contribution of dwellings; (3) their substitutions of price indexes; and (4) a utilization adjustment they introduce. I have already examined the weights (1); discussion of the utilization adjustment (4) is deferred to section VII.

The total effect of all their price substitutions (3) was to raise their 1950–62 growth rate of total input, and lower that of output per unit of input, by 0.23 percentage points [computed from 1, tables II and IV]. This calculation is based on use of their weights. Of this amount, in the neighborhood of 0.07 points derives from adjustment of construction. The remaining 0.16 points are due to substitutions of price series for producers' durables and inventories (almost entirely the former), which I regard as illegitimate. (It is partly offset by an output adjustment described in section VI below.)

The effect of (2), differences in measures of input (*other* than price substitutions for producers' durables and inventories), I can calculate only with the use of my weights—that is, the numbers refer to the change in my series that use of their input indexes would introduce. Of the difference between us in total input and output per unit of input, the difference in our measure of inventory input (excluding their price substitution) accounts for about 0.03 percentage points, and land indexes for none. Their nonresidential structures and equipment series rises enough more than the revised OBE series I would use to account for 0.07 points; both are based on the OBE II construction deflator. The difference in residential structures accounts for *minus* 0.12 points. The difference in capital stock measures (or their equivalent, in the case of dwellings) thus accounts for *minus* 0.02 points of the difference in our output per unit of input measures, based on my weights and apart from the effects of their price substitutions for producers' durables and inventories.

My incorporation of revised OBE data for nonresidential structures and equipment would *add* 0.04 points to the difference between us.

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47. The increase in gross product at factor cost, valued in 1958 prices, was put at $15.7 billion.

48. From 1950 to 1962, the Deflation II series rises less than the residential construction deflator, so the substitution implies that the bias in the deflator is downward in this period. This accounts for the negative adjustment in the growth rate of output that the following section shows is introduced by this price substitution. Over the longer time span reflected in the capital stock series, the adjustment is in the right direction.

49. This calculation supposes that about one-fourth of the weight I assign to dwellings pertains to sites, as distinguished from structures.

VI. Effect of Price Index Alterations on Output

JORGENSON and Griliches substitute investment price indexes in deflating the investment components of GNP as well as in measuring capital stock. The 1950–62 growth rate of their private domestic GNP is raised by 0.09 percentage points [calculated from 1, tables II and IV] and this partially offsets the deduction from output per unit of input they introduced by substituting prices in capital stock measurement.

To isolate the separate effects of their price substitutions on output, I duplicated their calculations. The breakdown of their adjustment is: producers' durable equipment 0.10; nonresidential structures 0.03; residential structures, −0.03; and inventories, 0.00. (The total, 0.10, presumably differs from their 0.09 because of rounding.) Thus, their entire output adjustment stems, on balance, from the use of consumers' durables prices to deflate producers' durables; none of it results from the legitimate attempt to adjust construction prices.

VII. The Utilization Adjustment for Capital and Land

MORE than half of the difference between our output per unit of input growth rates in 1950–62 results from an adjustment that Jorgenson and Griliches introduce for changes in utilization of capital and land. Their general idea is that the hours per year that capital is used have increased secularly, and that a given percentage increase in capital hours per dollar of capital has the same effect on output as a similar percentage increase in the quantity of capital. Their capital utilization adjustment raises the contribution of their total input series by 0.60 percentage points in their full 1945–65 period and by about 0.58 points in the 1950–62 period.[50] Their method of deriving this adjustment is theoretically unsound, and the statistical procedures they followed to obtain their estimates are altogether untenable. In my view, their capital utilization adjustment should be discarded.

Series for manufacturing equipment powered by electric motors

The starting point for the adjustment was a series contained in a 1963 SURVEY OF CURRENT BUSINESS article by Murray F. Foss [4]. Most production equipment in manufacturing is powered by electric motors. Foss used Census data for electric power consumption and the horsepower of electric motors to estimate the average number of hours per year that electric-power-driven equipment in manufacturing establishments was utilized. He concluded that its utilization increased by an amount on the order of one-third to one-half from the 1920's to the mid-1950's. The dates for which he made actual calculations were the Census years 1929, 1939, and 1954 [4, table 2, line 7]. Growth rates of average equipment hours calculated from his utilization estimates for these years are −0.45 from 1929 to 1939, 2.15 from 1939 to 1954, and 1.10 from 1929 to 1954. Jorgenson and Griliches made a similar comparison of the years 1954 and 1962 [1, table X, line 6]. From 1954 to 1962, the growth rate was 1.33. Jorgenson and Griliches used the 1939–54 rate for all annual changes in the 1945–54 period and the 1954–62 rate for all annual changes after 1954. They thus obtained average rates of increase in utilization of about 1.72 for 1945–65 and 1.60 for 1950–62.

These rates almost certainly are much higher than the trend rate, which is what Jorgenson and Griliches are seeking, or the rate that would be obtained if calculations could be made directly from the terminal years of these periods. The average rate from the depression year 1939 to 1954 must have been greatly raised by the difference in cyclical position; the rate from 1945 or 1950 to 1954 must have been much smaller than the rate over the 1939–54 period as a whole.[51] The rate from 1954, itself a recession year, to 1962 or 1965 probably was also raised by cyclical influences.[52] A minimal downward adjustment of their estimates to eliminate cyclical incomparability in the pre-1954 period could be made by substituting the 1929–54 rate where they use the 1939–54 rate. This would lower the 1945–65 growth rate of utilization from 1.72 to 1.22, and the 1950–62 rate from 1.60 to 1.25. Probably a better procedure would be to use the 1929–62 rate, which is 1.16, as representative of the trend throughout the period, hence for both the 1945–65 and 1950–62 periods; this would cut their 1950–62 rate by more than one-fourth and their

50. The 1945–65 figure of 0.60 points was provided by Jorgenson and Griliches; it can also be approximated from their published data.

The average growth rate of their capital utilization series itself was 1.72 in 1945–65 and 1.60 in 1950–62. (See the following text paragraph.) Multiplication of their 1950–62 growth rate of 1.60 by their average 1950–62 capital-land share of 0.36175 yields an estimated contribution of 0.58 percentage points.

(In this period, the combined contribution of their capital utilization adjustment and the labor hours adjustment was 0.52, thus the contribution of the labor adjustment was apparently about −0.06. I use this figure in section VIII.)

51. Foss himself wrote: "In fact, some of the illustrations in this article suggest that the major change in relative equipment utilization took place during and immediately after World War II, and that changes since then (aside from cyclical movements) have been relatively small" [4, p. 6].

52. Because Jorgenson and Griliches interpolate between far-removed dates rather than use annual estimates, the capital utilization adjustment obviously cannot purport to adjust capital input for shortrun variations in utilization. Jorgenson and Griliches note this and state that it "allows only for the trend in the relative utilization of capital" [1, p. 266]. My objection to their procedure is the same whether one construes their series as representing the trend rate in 1945–65 and 1950–62 or the actual changes from 1945 to 1965 and from 1950 to 1962.

1945–65 rate even more. Overstatement of the increase in this series from the absence of any procedure to deal with the cycle is, however, among the least of my objections to their utilization adjustment, and there is no need to pursue it further.

A second limitation is that the weights used to construct the all-manufacturing utilization series are inappropriate for the use to which Jorgenson and Griliches put it. "Available kilowatt hours of motors" were used as weights to combine utilization ratios for the component industries in obtaining the all-manufacturing utilization series.[53] For use in converting a series for the value of power-driven equipment in manufacturing establishments to a capital input series, the utilization ratios for all manufacturing should be based on the use of the *value* of power-driven equipment in each industry as that industry's weight. This was noted by Foss [4, p. 11] but is not mentioned by Jorgenson and Griliches. A series so constructed is not available for comparison, nor are the value data for power-driven equipment that its construction would require. Perhaps the two sets of weights would yield tolerably similar results; at the 2-digit level, Foss finds, with some exceptions, fair correspondence between distributions of *total fixed* capital and installed horsepower. Nevertheless, the possibility of appreciable error is present in the manufacturing series.

Equipment values are not available for mining either, but similar utilization ratios for the five mineral industries were published separately by Foss. Solely as an illustration that weights *may* matter, I calculated all-mining utilization ratios with alternative proxies for capital values. Use of "available kilowatt hours" as weights yields a 4 percent increase in utilization from 1929 to 1954, whereas use of "electric power consumed by motors" would yield a 16 percent decline. Like the manufacturing series, these calculations used 1929 weights for 1929 and 1954 weights for 1954. I argue subsequently that fixed weight indexes would be more appropriate. I calculated fixed weight indexes using four alternative sets of 1929 weights. Use of "value of machinery and equipment installed during 1929" yields a 14 percent increase in utilization from 1929 to 1954; "available kilowatt hours of motors" a 12 percent increase; "national income originating," a 2 percent increase; and "electric power consumed by motors," a 1 percent decrease. Probably the first two are better proxies than the last two for equipment values, but differences are large and investigation is needed.

In the absence of tests of its effects, the inappropriate weighting of the manufacturing equipment series adds to the reservations about the Jorgenson-Griliches use of this series that is created by their failure to allow for cyclical differences. But there is a fundamental conceptual objection to their use of this series to adjust capital input that would remain if value weights were used and cyclical adjustments were made. To develop this point, I shall proceed as if this had been done.

Conceptual problem of incorporating utilization data

The trend rate of capital utilization provides interesting information. But to integrate this information into the type of classification of growth sources that Jorgenson and Griliches or I employ, one must know the *reasons* that utilization increased and the *amount* due to each reason. Even if one knew exactly how much utilization had changed, in the absence of this additional information he still would not know the amount of the increase in output that (prior to any utilization adjustment) is included in the contribution of input (or any component of input) and the amount that is included in the contribution of output per unit of input. This is a subject that Jorgenson and Griliches do not discuss at all. However, their procedures imply that, prior to the introduction of their capital utilization adjustment, the effects of an increase in capital utilization necessarily appear only in their output per unit of input series.

The average hours "worked" by power-driven equipment in manufacturing establishments (adjusted to eliminate short-term fluctuations) may actually change for quite varied reasons, and these have altogether different implications for the analysis.[54]

1. The effects of some types of change are fully measured by the increase in the capital stock, so that any additional allowance for increased utilization duplicates the change in the capital stock measure. These types can be described as changes in composition of capital, of which three main categories can be distinguished.

(a) At any point in time, producers can select among varieties of equipment with different characteristics that sell at different prices. One characteristic that can be purchased at a higher price is greater reliability: longer use without downtime for regular maintenance or to replace worn-out or defective components or the entire machine. If producers shift to higher priced equipment, average "hours worked" will increase but so will the capital stock series. A priori there is reason to suppose that, as capital has become more abundant relative to labor, the use of more expensive equipment has been one aspect of the rising capital-labor ratio.

(b) At any point in time, different manufacturing industries vary in the hours they use capital. On the assumptions that Jorgenson and Griliches and I accept, the rate of return, as measured by the ratio of net earnings to net value, is, nevertheless, the same in each manufacturing industry. If hours in each industry are unchanged, but the weights of the industries alter, the average hours in manufacturing as a whole will change but capital input should not.

Suppose Industry A and Industry B each have $1 million of equipment, but

53. Foss confirms this statement, which the reader can check by use of Foss's ratios for mineral industries [4, table 6], for which the procedure was similar and for which industry data are shown. For minerals industries, Foss shows a five-industry breakdown. The all-industry utilization ratio in his column 8 is equal to the ratios for the individual industry groups weighted by "available kilowatt hours of motors" as shown in column 2.

54. Not all of these possibilities had occurred to me when I discussed capital utilization in *Why Growth Rates Differ* [2, pp. 154–155]. I would now word that section somewhat differently.

Industry A operates on three labor shifts, or 120 hours a week, and Industry B on one shift of 40 hours, and capital is used during the same time periods. Equilibrium requires the same rate of return in the two industries; otherwise, there would be an incentive for capital to move from one industry to the other. If the rate of return is 10 percent, the product (as indicated by earnings) of the $1 million of equipment in each industry is $100,000. The product of $1 million of equipment per hour it is used in a week must then be three times as high in Industry B as in Industry A ($2,500 against $833.33). This must be the case, or the rates of return would differ. If (because of changes in demand patterns or for other reasons) Industry B gets bigger relative to Industry A, average hours worked by equipment in the two industries combined will decline, whereas if Industry A gets bigger average hours will increase, because Jorgenson and Griliches use a capital utilization series that is constructed with shifting industry weights. They would therefore measure the former development as a decline in equipment input, the latter as an increase. This is a simple "error of aggregation." It results from giving an hour worked by $1 million of equipment in each industry the same weight.

To illustrate, suppose that in a second year the total value of equipment is $2,000,000, as before, but Industry A now has $1,500,000 and Industry B $500,000. Based on the use of capital stock to measure input, without a utilization adjustment, the contribution of equipment to output (in first-year values) remains $200,000; only the division between industries has changed—to $150,000 in Industry A and $50,000 in Industry B. This correct result could also be obtained by correctly weighting hours: The value of equipment (in millions) in each industry is multiplied by average weekly hours, and the contribution to output of an hour worked by $1 million of equipment is counted as $833.33 in Industry A and $2,500 in Industry B. In Industry A, equipment value times hours increased from 120 to 180; multiplication by $833.33 yields an increase in equipment's contribution from $100,000 to $150,000. In Industry B, equipment value times hours dropped from 40 to 20; multiplication by $2,500 yields a drop in the contribution of equipment from $100,000 to $50,000. The total contribution of equipment at first-year values is again $200,000 in both years.

In this example, the Jorgenson-Griliches procedure would erroneously yield an increase in equipment input of 25 percent, instead of no change, because it assigns equal weight to an hour worked in each industry.

Foss has investigated the effects of changes in industry weights in selected periods and concluded that the change in the all-manufacturing utilization ratio he observed chiefly reflected changes in individual industries rather than in industry mix, although he did note that there probably *was* a shift toward continuous process manufacturing industries, particularly aluminum, refined petroleum, and chemicals.

(c) At any point in time, the number of hours that different types of equipment are used varies widely *within* any establishment, firm, or industry. If the composition of assets changes, the average hours worked by all combined will rise or fall even though there is no change for any particular type. The hours for the same type of equipment may also vary among uses, and this distribution may change over time. These cases are identical to that discussed in (b). Greater use does not imply larger earnings per dollar of capital value. Two machines of different types (or of the same type in different uses) must be assumed to contribute equal amounts to production per dollar of value, not per dollar of value mutliplied by hours worked. If this assumption is invalid, rates of return vary and the economic unit is not in equilibrium. The sensitivity of a conglomerate average-hours-worked series to changes in weights of different types of machines, and to changes in weights of different uses of machines, must be high because the range of hours is large. Shifts of this type could well dominate the long-term movement of "average hours" series for individual firms, establishments, and industries.

Unless a capital utilization series can be standardized to eliminate the effects of *all three* types of "mix" changes, it is useless for the purpose to which Jorgenson and Griliches put it. I cannot imagine how such standardization could be achieved. But even if it could, this would surmount only one of the difficulties.

2. The amount of downtime of machines depends in part on the number of workers who operate them (which affects, among other things, the speed of machine operation), their skill, and the care they exercise. It depends also upon the number and skill of the workers who repair machines. The skill of engineers and others employed by equipment suppliers to service customers is often a crucial determinant of the amount of time lost from breakdowns. If machine hours increase because of an increase in the quantity or an improvement in the quality of labor, this is already counted in principle, and one hopes in practice, as a contribution of labor.

3. The amount of downtime depends in part on expenditures for maintenance. A firm presumably attempts to allocate expenditures among maintenance, purchases of new capital goods for replacement, and production labor in such a way as to minimize total cost. Maintenance expenditures may change because the price of maintenance changes relative to prices of capital goods and production workers; in this case, there is no ascertainable contribution to growth. Maintenance expenditures may also change because management devises a better procedure to determine the minimum cost combination. If they increase for this reason, only the *net* benefit remaining after deducting the increase in maintenance costs from the saving in capital and labor costs contributes to an increase in output.[55] Classification of any net benefit is discussed in case 7 below.

4. Downtime depends in part on the inventory of spare parts; any change is already covered as a contribution of

55. Unless output is measured on the Scandinavian "gross-gross-product" basis, which double counts maintenance as well as capital consumption.

inventories. It depends also on the speed with which parts and servicemen can be obtained; this, in turn, depends on capital and labor in the transportation industries, which are already counted as capital and labor input.[30]

5. The hours that machines are used may change because of a change in the average hours worked per worker; in my study I allow, in principle, for this effect in my adjustment of labor input for changes in labor hours of full-time workers [2, p. 61, n. 11]. (I found no significant change in labor hours of full-time workers in the economy as a whole over the period analyzed so this case did not actually affect my estimates.)

6. Machine hours may also change because shift work becomes more or less prevalent *in particular activities*. In my estimates, such a development was regarded as a component source of the change in output per unit of input [2, pp. 152–154, 173–174], and in my international comparisons, I made a specific estimate for this determinant. However, I found no evidence of a significant change in shift work in the United States in 1950–62, and therefore estimated the contribution of changes in shift work to be zero [2, pp. 152–154, 173–174].

7. The hours worked by machines may rise, or in some cases fall, because of advances of knowledge and its dispersion. These may:

(a) Provide more reliable machines without increasing their cost—a development variously described as "unmeasured" quality change in capital goods or "embodied" technical progress. (In practice, "measured" quality change covered in case 1(a) above and "unmeasured" quality change are often intertwined.)

(b) Enable management to make more continuous use of machines. Foss writes:

> "Also of importance over the long run has been the advance in knowledge acquired by management in making more efficient use of machines. One example of this has been the efforts by many firms to smooth out within the year the production peaks which come from seasonal or other short-lived peak loads and which frequently entail the use of standby equipment with relatively low annual utilization. . . . Within particular industries there have undoubtedly been efforts to introduce continuous, automatic operations in which machines tend to be used with a high degree of intensity."

(c) Improve communications and speed transportation of parts and of key personnel needed for repairs, notably by air.

(d) Improve the decisionmaking process generally—notably with respect to determination of the trade-off among costs incurred for maintenance, replacement, downtime, speed of operating machines, waste of materials, and quality of product.

This list of possible reasons for changes in average machine hours may not be exhaustive. But it suffices to make clear that, unless the reasons for changes in capital utilization are known and their effects can be isolated and quantified, data on capital utilization cannot be integrated into a classification of growth sources of the type Jorgenson and Griliches and I use. It is possible that the entire change indicated by the Jorgenson-Griliches series is already reflected in capital and labor input or counterbalanced by higher maintenance costs, and is not a component of the Jorgenson-Griliches output per unit of input series prior to their utilization adjustment, or of my series. Or any or all of it may be a component. Jorgenson and Griliches never mention, and appear unaware of, the range of possibilities.

Among the possible reasons for an increase in capital hours that I have listed, two would or might contribute to a change in output per unit of input as I measure it, and as Jorgenson and Griliches do prior to introduction of their utilization adjustment. The effects of one of these, changes in shift work in particular activities, I estimated [2, pp. 152–154] to be zero in the economy as a whole in 1950–62, though admittedly on the basis of inadequate information; better data may permit more reliable estimation in future years. The other is advances in knowledge and their dispersion. There is no clear presumption that these led to an increase in the hours that capital goods are utilized or that, if they did, the net saving in unit costs bore any systematic relationship to the change in machine hours. But if there was such an effect, it appears in the "advances of knowledge" component of my output per unit of input series. I see scant possibility that it will ever be possible to isolate this effect.

If one could isolate and measure this effect and the shift-work effect, one would have a choice of transferring them to the contribution of capital (evidently the Jorgenson-Griliches preference) or of classifying them as component sources of the growth of output per unit of input. The latter would be my preference because it is not the saving-investment process that governs these income determinants [2, p. 144], and I shall say a little more about this at the end of this article. But it would really make little difference to the sophisticated reader where they were shown because he could move them at will.

The Jorgenson-Griliches estimates

The Jorgenson-Griliches estimates implicitly assume (1) that the utilization series would be unchanged if weighted by value of power-driven machinery and (2) that the entire effect of increased utilization appears in their productivity measure until they make their utilization adjustment, hence that *only* advances in knowledge and changes in shift work *within industries* affected utilization of manufacturing equipment driven by electric motors. Since they do not diminish the growth of their capital stock series by

30. Parts of points 2 to 4 are nicely illustrated by an advertising letter that happened to reach me as I was writing this section. It states:

"Are you aware that the . . . Corporation has for the past fifteen years been providing preventive and corrective maintenance to a growing number of manufacturers and users of electronic and electromechanical devices?

"Our experience in performing both scheduled and emergency service (supported by factory-trained personnel, local stocking of replacement parts, and quick response to emergency calls) aims to improve your operation in terms of lower 'down-time' and higher reliability."

shortening service lives as they increase capital utilization, they also assume (3) that increased utilization does not cause equipment to wear out more rapidly. (If there is such a user cost, the utilization adjustment duplicates their original estimate of the contribution of capital for this reason.)

I know of no reason to accept this set of assumptions. But it is instructive to calculate what the quantitative importance of the change in utilization of power-driven equipment in manufacturing would be if by chance all these assumptions were correct. First, the weight in total input must be calculated. *All* nonresidential structures and equipment represented 13.6 percent of total input in the private domestic economy in 1950–62, according to my net earnings weights. *All* producers' durables in manufacturing establishments represented about 14 percent of the value of the total stock of private nonresidential structures and equipment, hence 1.9 percent of total input. Machinery in manufacturing establishments driven by electric motors represented at the outside 70 percent of the value of the stock of producers' durables in manufacturing establishments in 1950–62, hence at most 1.4 percent of total input. If the utilization of such machinery increased 1.16 percent a year (the figure I suggested earlier as the trend rate of the utilization series), and if an increase in utilization is treated (as Jorgenson and Griliches *do* treat it) as equivalent to the same percentage increase in the quantity of such equipment, this raises the growth rate of total input (net product basis) in the private domestic economy by 0.016 percentage points (1.4 percent of 1.16 percent) and lowers that of output per unit of input by the same amount. This would be my estimate if I were to accept the Jorgenson-Griliches utilization estimates and their three implicit assumptions mentioned in the preceding paragraph (which, of course, I do not). Even with the Jorgenson-Griliches utilization increase of 1.60 percent a year, the contribution is only 0.022 percentage points in 1950–62. If, as in the Jorgenson-Griliches estimates, depreciation is added to the weights, the calculated contribution to gross product growth would probably come up to 0.03.

How do Jorgenson and Griliches get from 0.03 to 0.58? By introducing the "very strong assumption" (their language) that utilization of *all* types of capital and land in *all* activities increased at the same rate as did machinery in manufacturing establishments driven by electric motors! This assumption is not only "very strong"; it is truly magnificent in its implausibility. Utilization of structures, sites, furniture, and office equipment in manufacturing, of office buildings, of physicians' automobiles, of houses and their sites, of railroad stations, of farmland (have the seasons changed?), of inventories (whatever this may mean), of literally everything has increased, and at the same rate as machinery driven by electric motors in manufacturing establishments!

If one is willing to assume that the change in machinery hours in manufacturing was due only to advances in knowledge and changes in shift work within industries, he might perhaps, I suppose, go even further and assume there was some net increase in *machinery* hours outside manufacturing after 1950, and thus raise the figure derived from the manufacturing series a little. Foss found some examples of machinery in nonmanufacturing industries in which utilization increased from the 1920's to the 1950's as well as some where it did not. For example, in two of five mining industries, utilization of power-driven equipment increased from 1929 to 1954 while in three it declined, although it should be noted again that these years are not cyclically comparable.[57] Locomotive use increased while freight car use decreased. Utilization in electric utilities increased from the late 1930's to 1948, but not from 1948 to 1958. And so on. But even doubling the manufacturing figure would yield no more than 0.06 points in their gross product growth rate. Jorgenson and Griliches have applied the increase in utilization not only to all machinery but to all other types of capital and to land. Since all capital and land received 36.2 percent of their total input weight (inclusive of depreciation as well as indirect taxes), this raised the contribution of the utilization adjustment from 0.03 to 0.58 (36.2 percent of 1.60).

The conclusion to be drawn from the preceding discussion—it seems to me inescapable—is that the Jorgenson-Griliches utilization adjustment must be rejected.

After this summation, it may seem superfluous to mention that the Jorgenson-Griliches procedures also contain an important inconsistency. Houses and sites represent a huge part of the stock of capital and land, and much of the capital utilization adjustment reflects the assumption that the hours houses are used have increased. Even if Jorgenson and Griliches were right to assume that people have been spending an increasing amount of time in their houses, per dollar value in constant prices of house, this would not affect their output measure because (fortunately) OBE does not adjust its deflated consumer expenditure series for housing to allow for the supposed increased utilization, and Jorgenson and Griliches do not adjust the OBE series on this account. Hence, Jorgenson and Griliches are arithmetically wrong to subtract the utilization adjustment for residential structures and the residential portion of their land input from the growth of productivity.[58]

57. The Foss series for all mineral industries rises (but its 1929–54 growth rate is only 0.17 as compared with 1.10 for manufacturing) because of a very sharp increase in nonmetal mining, which receives a rather heavy weight (20 percent of the total in 1929 and 27 in 1954) based on available kilowatt hours of motors.

58. Let me stress that my criticisms of the Jorgenson-Griliches utilization adjustment do not extend to the article by Foss, which I have praised in print on several occasions. Nor do I mean to deny the value and relevance to growth studies of series of the type that Foss prepared for power-driven equipment in manufacturing and mining industries and a few other types of fixed capital and that might be prepared for additional types. Indeed, like Jorgenson and Griliches, I should be very glad to see such studies extended. I believe Foss is correct in suggesting [4, p. 10] their importance for analysis of long-term changes in capital-output ratios. Studies of shift work would be immediately useful. More generally, the fact that capital utilization series do not easily fit into the type of classification discussed in this article does not imply that one cannot fruitfully explore the relationship between changes in capital utilization and economic growth. There may be a valid analogy with studies, obviously valuable, of such questions as: "How does transportation affect growth?" or "How did high wages in the United States affect American as compared with European growth in the nineteenth century?" Studies of these questions, too, do not yield results that fit into the type of classification of growth sources that is examined here.

VIII. The Measurement of Labor Input

JORGENSON and Griliches and I measure labor input in ways that are similar in spirit and general approach. Both our input series take into account employment; hours worked, with an allowance for a productivity offset as hours change; and the education of the labor force. My series allows, in addition, for changes in the distribution of total hours worked among age-sex groups whereas theirs does not, but Jorgenson and Griliches agree that this should be done [1, p. 269].[59] Thus a comparison does not raise major conceptual issues.

However, the data and procedures we actually use to measure labor input differ at almost every step, and it is necessary to consider whether this introduces a difference into our estimates of productivity change. My conclusion is that our labor input series are in rather close agreement with respect to the common elements of our estimates, after allowance for my inclusion of government employees.[60] Their omission of an age-sex measure contributes to their higher estimate of the growth of output per unit of input.

Employment, hours, and education

Because of a difference in classification with respect to employment and hours effects, it is desirable to combine the two for comparison. It is also necessary to build up a comparison in several parts.

My employment series is based on household survey data from the *Monthly Report on the Labor Force*. Jorgenson and Griliches rely on the OBE series for persons engaged in production, which is the sum of its full-time equivalent employees and active proprietors of unincorporated enterprises. This series is mainly constructed from establishment reports.

I have attempted to compare data from the two sources at the all-civilian-employment level to try to determine whether movements of the two series are statistically consistent from 1950 to 1962. My series for civilian employment has a 1950–62 growth rate of 1.03.[61] To obtain a conceptually similar series for comparison, I start with OBE series on persons engaged in production, excluding military employment; substitute the OBE series for full-time and part-time employees for full-time equivalent employees; add my estimates for unpaid family workers; and adjust the 1962 figure to exclude Alaska and Hawaii by application of a 1960 overlap ratio. The resulting series has a 1950–62 growth rate of 1.00. For this timespan, the *statistical* difference between MRLF and OBE data would, by this test, make the Jorgenson-Griliches employment series grow 0.03 less than mine. However, Jorgenson and Griliches omit unpaid family workers. The 1950–62 growth rate of their employment series for private industries would be lowered by 0.06 if my estimates for unpaid family workers were added to their estimates. The two differences together would make their series grow 0.03 more than mine.

We each estimate the effect of changes in hours worked by measuring changes in average hours, and allowing for a productivity offset as hours of full-time workers decline. For civilian workers, my resulting series for the effect of changes in hours upon the work done in a year of employment has a growth rate of −0.25 from 1950 to 1962 [2, table 6–6, and an adjustment to exclude military personnel]. This figure includes the effect of a major increase in part-time employment; in fact, it mainly reflects the effect on hours of an increasing part-time component of employment, as distinguished from changes in hours of full-time workers. Two figures from the Jorgenson-Griliches estimates must be combined for comparison. Their series for the effect of hours on the work done in a year of *full-time* employment has a growth rate of about −0.09 from 1950 to 1962.[62] The increase in part-time work is reflected in the employment component of the Jorgenson-Griliches labor input series because their employment series is computed on a full-time equivalent basis. The 1950–62 growth rate of the OBE persons engaged series for private industries is lower by 0.23 than that of an otherwise similar series in which the OBE series for full-time and part-time employees is substituted for full-time equivalent employees. Thus, the combined effect of changes in full-time hours and increased part-time employment on the Jorgenson-Griliches labor input series is −0.32 (−0.09 plus −0.23), which compares with my −0.25. When the difference of −0.07 is added to the 0.03 difference in the employment growth rates, it appears that the difference between our employment and hours series makes their labor input series grow 0.04 points less than mine. Based on their 1950–62 average labor share, this would make their estimate of the contribution of total input 0.03 points lower, and of output per unit of input 0.03 higher, than use of my series.[63]

59. They also say that the labor input series should, in addition, be standardized by occupation and industry. In my view, this is a conceptual error, but since they did not do this, no discrepancy between our estimates is introduced.

60. To adjust for the difference in the scope of our employment estimates, I use OBE data for general government employment. This is appropriate because these data are consistent with the government product data used in Section I above to reconcile productivity estimates. The difference in the scope of our estimates causes little difficulty in comparing other components of our labor input series because, with unimportant exceptions, we each assume that changes are the same for total private employment as for total civilian employment.

61. Computed from 2, tables 5–1A, 5–1C, 5–1D, and C–1. In my estimates, all series are linked at 1960 to eliminate the effect of adding Alaska and Hawaii to coverage of the data.

62. In footnote 50, I calculated that their hours adjustment for labor amounted to −0.06 percentage points in the growth rate of total input. Division of this amount by their average labor share of 0.639 in 1950–62 yields −0.09.

63. I have not isolated the effect of one of their procedures in this reconciliation of our estimates. Although unpaid family workers are excluded from the Jorgenson-Griliches employment series, they do affect total labor input via the hours estimates. Jorgenson and Griliches inform me that they obtained average hours by dividing the BLS establishment-based series for total manhours worked in the private economy (which includes unpaid family workers) by persons engaged in production (which excludes unpaid family workers). Hence, the decline in the ratio of unpaid family workers to total employment presumably intensifies the decline in their average hours series. This reduces the growth in labor input insofar as it was not offset by their efficiency adjustment.

We each estimate the effect of the rise in education upon the quality of labor. The growth rate of my "education quality" series for civilian employment is 0.75 [2, table 8-5]. Despite procedural differences, their rate is also 0.75 [computed from 1, table VII]. No discrepancy in our labor input series is introduced by education.

Age-sex composition

My "quality index" for changes in the age and sex composition of hours worked by civilian employees has a −0.15 growth rate from 1950 to 1962 [2, table 7-7, and an adjustment to exclude military personnel]. Jorgenson and Griliches omit this labor characteristic from their measure. Based on their average 1950-62 labor share, the omission causes their total input series to grow 0.11 points more than mine from 1950 to 1962, and their output per unit of input series 0.11 points less.

IX. Summary of Statistical Review

AN approximate reconciliation of our output per unit of input estimates can now be compiled. It is provided in table 1.

The initial difference between our estimates is 1.27 percentage points (line 3). When my estimates are adjusted to conform to the definition and scope of output used by Jorgenson and Griliches, and their estimates are adjusted to my time period, the difference is reduced to 1.08 (line 6). If my estimates are adjusted to incorporate revised OBE data for the stock of nonresidential structures and equipment, including use of the OBE Deflation II series for nonresidential structures, the difference between us is widened to 1.12 percentage points (line 9).

I found only one significant difference in our classifications of growth sources, as between input and output per unit of input. My input series is broader in that it includes the effect on labor "quality" of shifts in the age-sex composition of hours worked, whereas such shifts affect the Jorgenson-Griliches series for output per unit of input. This source made a negative contribution to growth in 1950-62, so that adjustment of their output per unit of input series to my classification narrows the difference between us from 1.12 to 1.01 percentage points (line 12).

The remaining 1.01 points, which are divided among components in lines 13 to 20, result from differences in statistical procedures. These are of two types: differences in weights and differences in input measures.

Not all of the difference between our weights is relevant here; the portion that is due to inclusion by Jorgenson and Griliches of depreciation and the portion that is due to their exclusion of government and the international sector are related to the difference in output measures, and their effects were previously eliminated in moving from line 3 to line 6. (There is one exception: The effect on the capital utilization adjustment of including depreciation in the weights was not eliminated and is included in the effect of the capital utilization adjustment in line 18.)

The division of the 1.01 points in lines 13 to 20 is, in principle, that which results from first measuring the effect upon my series of substituting their weights for mine and then measuring the effects of substituting their

Table 1.—Reconciliation of Denison and Jorgenson-Griliches Estimates of the Growth Rate (or Contribution to Growth) of Output per Unit of Input (Percentage points)

Reported output per unit of input growth rates:		
1. Denison, total national income, 1950-62 (p. 1)		1.37
2. Jorgenson-Griliches, private domestic GNP, 1945-65 (p. 1)		.10
3. Difference 1-2		1.27
Rates adjusted for definition and scope of output and time period:		
4. Denison, private domestic GNP, 1950-62 (p. 8)		1.38
5. Jorgenson-Griliches, private domestic GNP, 1950-62 (p. 2)		.30
6. Difference 4-5		1.08
Rate adjusted for new data:		
7. Adjustment of Denison series to incorporate new "structures and equipment" data (p. 16)		.04
8. Denison, private domestic GNP, 1950-62, adjusted, 4+7		1.42
9. Difference 8-5		1.12
Rate adjusted for difference in classification:		
10. Adjustment of Jorgenson-Griliches series to eliminate effect of changes in "labor quality" due to shift in age-sex composition of hours worked a, c (p. 24)		−.11
11. Jorgenson-Griliches, private domestic GNP, 1950-62, classification adjusted 5-10		.41
12. Difference 8-11		1.01
Breakdown of remaining difference of 1.01:		
13. Difference in division of input weights between labor and capital-land b, c (p. 5)		.08
14. Difference in inventory capital stock series d (p. 14)		.03
15. Difference in nonresidential structures and equipment capital stock series d (p. 16)		.07
16. Difference in residential structures procedure d (p. 17)		−.12
17. Jorgenson-Griliches substitutions of price indexes for equipment and inventories, net effect e		.07
Effect via output	−0.09 (p. 18)	
Effect via input c	.16 (p. 17)	
18. Jorgenson-Griliches capital-land utilization adjustment a (p. 18)		.58
19. Difference in estimates of employment and hours (p. 22)		−.03
20. Other differences f		.33

a Amount calculated with Jorgenson-Griliches weights.

b Reflects the net effect on the Jorgenson-Griliches weights of (1) counting as capital-land earnings all indirect taxes and other reconciliation items between factor cost and market price measures and (2) allocating to capital-land earnings a smaller portion than Denison of proprietors' income.

c Calculation based on Denison input series.

d Amount calculated with Denison weights.

e The construction price substitutions had no effect on output. Their effect on input is already taken into account in lines 7, 15, and 16.

f This estimate was obtained as a residual.

To obtain a full reconciliation it would have been necessary after line 9 to measure (1) the changes in my estimates that would have been introduced by my use of the Jorgenson-Griliches weights (except for depreciation) and (2) to measure the effect on their estimates, based on their weights, of the differences between us in measuring inputs. The first could be done for the division of weights between labor and capital-land, but not within the capital-land aggregate. The second could be done for most differences, but lines 14 to 16 were calculated by use of my weights instead of theirs. Line 20 therefore includes:

1. The effects of differences in the allocation of the total capital-land weight among components, including the consequences of the Denison division of the economy among sectors and the Jorgenson-Griliches adjustment for capital gains and taxes.
2. The difference between the amounts shown in lines 14, 15, and 16 and the amounts that would be obtained in these lines if Jorgenson-Griliches weights were used in the calculation instead of the Denison weights.
3. Possible errors in the calculations of amounts shown in several other lines of this table resulting from my use of average 1950-62 weights instead of annual weights (in the case of Jorgenson-Griliches estimates) or 1950-54, 1955-59, and 1960-62 weights (in the case of the Denison estimates) to calculate differences.
4. Rounding discrepancies.

input measures for mine when their weights are used; the breakdown would be different if the order were reversed. Two departures from this principle should be noted. The effect of a different allocation of total net capital-land earnings among components, the principal subject of section IV, was not measured and is included in "other differences" in line 20. Also, the effect of using different capital stock series (or a different method in the case of dwellings) could be measured only with the use of my weights (lines 14, 15, 16), and the difference between these results and those that would be obtained with their weights is also included in "other differences" in line 20.

The difference between us of 1.01 points shown in line 12 would be 1.04 were it not for a small offset (line 19) flowing from a difference in our estimates of employment and hours, which I did not evaluate. I have presented what I regard as compelling reasons to consider each of their procedures that contributes to this discrepancy as inferior. Nothing in their article suggests to me a change in my estimates.

Well over half of the entire statistical difference stems from the Jorgenson-Griliches utilization adjustment for capital and land (line 18). If increased utilization of capital and land resulting from advances in knowledge had really contributed 0.58 percentage points to the growth rate, then this amount would be regarded as due to classification rather than to statistical procedure. I have stressed my reasons for concluding that this is not the case. Although the portion of the total gains from advances in knowledge that is transmitted to higher productivity by the mechanism of lengthening capital hours simply cannot be estimated from available information, an amount larger than, say, 0.02 or 0.03 points in the 1950–62 growth rate seems improbable. I therefore classify the Jorgenson-Griliches utilization adjustment of 0.58 as resulting from differences in statistical procedure rather than in classification.

X. Some General Observations

JORGENSON and Griliches draw certain conclusions from their results that I believe to be unsupported and unsupportable.

To introduce this discussion, let me first recall that, in the framework of my estimates, output per unit of input in the private domestic economy may rise, or fall if changes are adverse, for any of a large number of reasons. Seven are perhaps worth listing. Having concluded that Jorgenson and Griliches do not have a broader classification of inputs than mine, I consider that all apply equally to their estimates.

1. Advances in technical, managerial, and organizational knowledge permit more output to be obtained with a given quantity of inputs. The gains may take the form of making possible production of more efficient capital goods at the same cost (resulting in "embodied" technological progress) or they may take any other form. Advances in knowledge, whether transmitted through improvements in capital goods or not, may result from expensive research at one extreme or from completely cost-free accidental discoveries at the other.

2. Knowledge may become more quickly or widely dispersed.

3. Expansion of markets may permit economies of scale.

4. The allocation of resources may move closer to the allocation that would maximize output. Allocation has a myriad of aspects ranging from the distribution of total resources among industries, products, and firms of different size to the placement of each individual worker in the particular job in which his contribution is greatest.

5. Obstacles deliberately imposed by governments, business, or labor unions against the most efficient utilization of resources in the use to which they are put may weaken.

6. The adequacy of government services (roads, police, courts, etc.) that affect private productivity may change.

7. The intensity of utilization of resources may change cyclically with variations in the pressure of demand [2, pp. 273–277, 441–442]. (I try to eliminate the effects in presenting "adjusted" growth rates of output per unit of input.)

My statistical estimates of output per unit of input may also rise or fall because my measures of input are incomplete (for example, I could not measure how hard people work) or inexact. In presenting my estimates, I have always tried to stress the limitations of information and technique, and the fact that one cannot proceed with growth analysis without introducing some assumptions. He can only try to adopt assumptions that are as realistic as he can make them. In this article, I have considered only differences between the Jorgenson-Griliches techniques, data, and assumptions and my own. I have not considered the limitations of techniques and assumptions that we share.

Interpretation of Jorgenson-Griliches results

Jorgenson and Griliches introduce their article by stating that its purpose is to test the hypothesis that "if real product and real factor input are accurately accounted for, the observed growth in total factor productivity is negligible." [1, p. 249] Their small estimate of the rise in total output per unit of input leads them to "conclude that our hypothesis is consistent with the facts." From this conclusion, they draw sweeping inferences. My conclusion is that they obtain their strikingly low estimate of productivity growth not by eliminating errors made in other research but by introducing new errors of their own. If so, the inferences they draw from this finding are also wrong.

I have stressed that the determinants of changes in output per unit of input are the same for the Jorgenson-Griliches series as for mine.[64] I am unable to find anything in their procedures that would have the effect of reclassifying a growth

64. Except that they also include changes in labor quality due to changes in age-sex composition.

source that I consider to be a component of output per unit of input into a component of input except their wholly unwarranted capital utilization adjustment. Nevertheless, their theoretical discussion suggests that Jorgenson and Griliches would like to reclassify growth sources from productivity to input. Some readers of their article have supposed that they have actually done so; this is understandable because Jorgenson and Griliches are not very clear on this matter.

Their discussion [1, p. 260] of "vintages" of capital goods is likely to mislead the unwary reader. This discussion is concerned with the fact that the design of capital goods improves as time passes. For this reason, an investment of a given sum this year buys a bundle of capital goods that is more productive than the bundle that could have been purchased this year with the same sum of money if capital goods of designs known 10 or 20 years ago were now being produced and were the only types known and available.

Jorgenson and Griliches indicate that, to aggregate capital goods in the capital stock, they would like to treat capital goods of different vintages as different commodities and weight them by their marginal products at a common date, rather than weight them by their costs at a common date as is the general practice in existing capital stock series. This procedure would be equivalent to adjusting existing capital stock series to reflect "unmeasured" quality change; "unmeasured" quality change in the capital stock is defined as the difference in movement between a capital stock series constructed by weighting components by marginal products and a series in which costs are used as weights [2, pp. 134–135, 144–145]. The contribution of "unmeasured" quality change to growth is "embodied technical progress." Thus, the procedure Jorgenson and Griliches recommend would have the effect of transferring "embodied technical progress" from the productivity to the input measure.[65]

It is difficult to read their article without supposing that they actually do make such a transfer.[66] But they stop short of making this claim explicit. In actual fact, I find nothing in their procedures that has the effect of adjusting capital input for the type of quality change that is not reflected in cost differences at a common date, and thus of "embodying" technical progress (nor am I aware of any statistical procedure that could be introduced to do this). I have taken pains to point out that neither their price substitutions nor their use of a fast depreciation (replacement) formula in measuring capital stock has any such effect.

It should also be noted that a distinction they introduce between costly and "costless" advances in "applied technology, managerial efficiency, and industrial organization" [1, p. 250] plays no role in their estimating procedure. They do not capitalize the costs or benefits of research and development, of reallocation of labor, or of any other action that would contribute to an increase in output per unit. Thus, they have transferred none of the gains from costly research or from other expenditures or costly actions out of their estimates of output per unit of input.

Given the characteristics of their productivity estimates that I have described, how is one to interpret the following passage, which appears after their empirical results are presented?

> "Our results suggest that the residual change in total factor productivity, which Denison attributes to Advance in knowledge, is small.[67] Our conclusion is not that advances in knowledge are negligible, but that the accumulation of knowledge is governed by the same economic laws as any other process of capital accumulation. Costs must be incurred if benefits are to be achieved. Although we have made no attempt to isolate the effects of expenditures on research and development from expenditures on other types of current inputs or investment goods, our results suggest that social rates of return to this type of investment are comparable to rates of return on other types of investment. Another implication of our results is that discrepancies between private and social returns to investment in physical capital may play a relatively minor role in explaining economic growth." [1, p. 274]

This quotation seems to contain four statements. Even if the Jorgenson-Griliches statistical results were accurate, they would not, I believe, support all of these statements. Indeed, the interpretation of their residual productivity estimate that is required for it to support the first statement seems directly contrary to the interpretation that would be required for it to lend any support to the other three statements.

The first statement is that the small Jorgenson-Griliches residual does not imply a small contribution to growth from advances in knowledge. This statement could be correct *only* if their procedures *have* the effect of reclassifying much of what I regard as the contribution of output per unit of input to an input contribution. In the absence of such a reclassification, a tiny figure for growth of output per unit of input *would* in fact leave little room for a contribution from advances in knowledge—or from economics of scale, reallocation of resources, or any of the

65. Jorgenson and Griliches would like to allow for "unmeasured quality change" of capital goods in computing the fixed investment components of GNP at constant prices as well as in constructing capital stock series. This would not affect the amount transferred from "GNP per unit of input" to input as "embodied technical progress," but by raising the growth rate of gross product, it would offset to some degree the reduction of the productivity series. However, three points should be noted. (1) The addition to growth of GNP per unit of input would tend to be much smaller, on the average, than the deduction because the ratio of gross fixed investment to GNP is much smaller than the fixed investment share of gross earnings, especially when the latter includes indirect taxes. [See 1, p. 262.] (2) In an analysis of net product growth, most of the addition to productivity (but not of the subtraction) would disappear because the increase in the growth rate of gross output in constant prices would be accompanied by a corresponding increase in the growth rate of depreciation in constant prices. (3) The relative size of the positive and negative adjustments to GNP per unit of input would change from time to time unless (a) the rate of "unmeasured quality improvement" were constant over a long period (from the installation date of the oldest capital in the stock when output is first measured to the last date that output is measured) and (b) changes in the share of fixed investment in output synchronized with changes in the share of fixed investment in earnings in some very special way.

66. Their footnote 1 on p. 254, does not contradict this. It merely states that they do not measure embodied technical progress in such a way as to make the change in output per unit of input zero by definition. Their footnote 1, p. 274, refers to errors in capital goods prices, which they try to correct, as "analogous to embodied technical change."

67. Footnote by Denison: Actually, I have attributed to advances in knowledge only part of my estimate of the contribution of output per unit of input.

other sources I have listed as contributing to changes in output per unit of input.

The second statement is that, to obtain important advances in knowledge, commensurate costs must be incurred; costs must be incurred if benefits are to be achieved. This implies that a comparison of costs and gains has been made. Actually, Jorgenson and Griliches provide no estimates at all of the *costs* of obtaining knowledge—e.g., costs of research or exploration. The fact that their residual productivity estimate is small can indicate that *gains* from advances in knowledge—whether costly or costless—are small *only* if Jorgenson and Griliches *have not* transferred gains from advances in knowledge from productivity to input. I would regard as implausible a finding that advances in knowledge have contributed to growth an amount as small as their residual.[68] I have tried to show that their estimate actually results from procedural and statistical errors. But, although I have argued that Jorgenson and Griliches have made no *valid* transfers of growth sources from productivity to input, the actual reason their residual is so very small is their introduction of the capital utilization adjustment. If this adjustment were really accurate and appropriate, they would have counted gains (their estimate implies *most* of the gains) resulting from advances in knowledge as a contribution of capital. If they had succeeded in adjusting capital stock series for unmeasured quality change by their "vintage" approach, this too would have counted gains resulting from advances in knowledge as a contribution of capital.[69]

The third statement is that social rates of return on research and development are comparable to those on other types of investment. This statement, too, does not follow from their results. As just indicated, they provide neither measures of the costs of research and development for comparison with costs of tangible investment, nor measures of the benefits of research and development and of tangible investment.

As to their fourth point, I do not understand how their results could possibly show that discrepancies between private and social returns to investment in physical capital are small. Jorgenson and Griliches must somehow have drawn this inference from the size of their residual. But their introduction of a capital utilization adjustment renders use of their residual for inferences about social rates of return conceptually invalid, just as it does for inferences about returns to research. And even their small residual would be big enough to add greatly to the private rate of return on investment if (improbably) it arose entirely from the discrepancy between public and private returns to investment.

Part of the difficulty with the quotation I have just analyzed stems from the preference of Jorgenson and Griliches for what I regard as an inconvenient classification of growth sources, and this leads me to a final comment on this topic. I believe there is an advantage in matching growth sources with the reasons that income changes, and I have tried to adhere to this principle in my own work. In particular, confusion and misinterpretation are avoided if the contribution of capital is identified with changes in income that result from investment, and that can be altered by changing the amount of investment, and the contribution of advances in knowledge is identified with changes in income that result from advances in technical and managerial knowledge, and that can be altered by changing the state of knowledge. Confusion is hard to avoid if the consequences of advances in knowledge are classified as contributions of capital. This is why I believe it would be unwise, even if they could be isolated, to count as contributions of capital the gains made possible because someone has devised improved designs of capital goods, or found ways to make possible more continuous use of capital goods. Such a classification is an invitation to misinterpretation.

68. It may be noted that Jorgenson and Griliches have estimated that the increase in output per unit of input was negligible over the whole 1929–64 period as well as during the postwar period [5, p. 61]. They clearly believe this to be the typical situation.

69. If the superiority of later "vintages" of capital goods was that they could be used longer hours, the same gains would actually be transferred twice—once by the capital utilization adjustment, and once by the adjustment of the quality of capital.

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By DALE W. JORGENSON and ZVI GRILICHES

Issues in Growth Accounting: A Reply to Edward F. Denison

1. Introduction

In our paper, "The Explanation of Productivity Change" [60], we examine the measurement of total factor productivity from the perspective provided by the economic theory of production. From the accounting point of view the major innovation in our approach is in the integration of productivity measurement with national accounts for income, saving, and wealth. Our main substantive conclusion is that growth in real factor input rather than growth in total factor productivity is the predominant source of growth in real product.

Both our approach to productivity measurement and our substantive conclusions require much further analysis and testing. Edward F. Denison has made an important contribution to this further analysis and testing in his paper, "Some Major Issues in Productivity Analysis: An Examination of Estimates by Jorgenson and Griliches" [25]. In this paper Denison examines our approach from the vantage point of methods developed in his study, *Why Growth Rates Differ* [28]. Denison's contribution is especially valuable since his objectives are similar to ours and his approach is carefully articulated with national income and expenditure accounts.

NOTE.—Professors Jorgenson and Griliches are both members of the Department of Economics, Harvard University. A version of this paper was presented at the 12th Conference of the International Association for Research in Income and Wealth in Ronneby, Sweden, August 30–September 4, 1971.

Although Denison's objectives and our objectives are similar, any attempt to integrate his approach to productivity measurement into national accounts for saving and wealth gives rise to serious difficulties. The first important difficulty arises from a basic confusion between depreciation and replacement that underlies all of Denison's work. Denison measures net national product as gross product less replacement; the correct definition is gross product less depreciation. The error in measurement of total product carries over to Denison's measure of total factor input, since the value of total product is equal to the value of total factor input as an accounting identity.

A second important difficulty in Denison's approach arises from an inconsistency between his treatment of depreciation in the measurement of total product and his treatment of replacement in the measurement of capital input. This inconsistency results in a contradiction between the income accounts that underlie productivity measurement and the wealth accounts that underlie the measurement of capital input. Although Denison's measure of total factor productivity is consistent with national income and expenditure accounts, it is impossible to integrate his measure into national saving and wealth accounts.

Further difficulties arise in Denison's allocation of property income among assets. First, Denison employs nominal rates of return rather than real rates of return in measuring income from the supply of capital services. As a consequence his allocation of property income among assets is inconsistent with the integration of property income into accounts for saving and wealth. Second, Denison's classification of assets ignores important differences in direct taxation of property income by legal form of organization. His allocation of property income fails to reflect the impact of the tax structure on rates of return of different types of assets.

The purpose of this paper is to compare our approach to productivity measurement with Denison's. For this purpose we present a new set of estimates of total factor productivity for the period 1950–1962 covered in Denison's study, *Why Growth Rates Differ* [28]. These estimates, prepared by Christensen and Jorgenson,[1] implement our approach in much greater detail than the estimates given in our earlier study. The new estimates and the methods employed in obtaining them are presented in Sections 2–6 below. In Section 7 we compare these results with Denison's and our own earlier ones and assess the quantitative importance of the differences.

The first step in productivity measurement is to define measures of product and factor input in current prices. Product is divided between consumption and investment; factor input is divided between labor and capital input. Investment and capital input are linked through national accounts for saving and wealth. Investment in reproducible tangible capital assets is part of the national product and also part of saving. Investment less depreciation plus capital gains is equal to the change in the value of the corresponding capital asset from period to period.

Capital assets underlie capital services. The treatment of capital assets as part of wealth must be consistent with the treatment of capital services as part of factor input. An important objective of our approach to productivity measurement is the integration of capital input into national accounts for income, saving, and wealth. Our estimates of product and factor input, consumption and investment, and labor and capital services are presented in Section 2 below.

In Section 3 we present estimates of capital input implementing our approach in much greater detail than in our original study. The new estimates permit us to distinguish among components of property income corresponding to sectors of the economy that differ in legal form of organization. These estimates provide for a much more staisfactory integration of direct taxation of property income into factor input accounts.

We have attempted to validate our original measures by checking our data against a more comprehensive body of supplementary evidence—especially evidence on investment goods prices in Section 3 and data on changes in the relative utilization of capital in Section 4. In constructing a new set of estimates Christensen and Jorgenson have been able to incorporate new data. In the most difficult area of empirical research, the measurement of relative utilization, they incorporate cyclical as well as secular changes in relative utilization into their measure of capital input.[2] In reviewing their work in Section 4 and in response to Denison's comments we have reached the conclusion that the scope of our original adjustments for changes in relative utilization should be reduced.

In the measurement of real factor input, rates of growth of labor and capital input are averaged to obtain the rate of growth of total factor input, using relative factor shares as weights. The measurement of aggregate labor input as developed by Denison, Griliches, and others,[3] amounts to applying the same principle of aggregation to the individual components of labor input. Rates of growth of the components are averaged to obtain the rate of growth of total labor input, using relative shares in the value of labor input as weights. Our measure of labor input does not differ conceptually from the measure employed by Denison. Even though the details of the measurement procedure are quite different for the two estimates, the empirical results are very similar. Both measures of labor input differ substantially from measures based on unweighted man-hours, such as those of Abramovitz [1], Kendrick [61, 62] and Solow [70]. In Section 5 we compare our measure of labor input with alternatives incorporating additional detail.

In Section 6 we present revised estimates of total factor productivity. Revised estimates of capital input require data on property income by legal form of organization, an analysis of the tax structure for property income, and the incorporation of measures of relative utilization of capital stock. Estimates of capital stock already incorporated into productivity studies provide an important part of the empirical basis for revised estimates of capital input. Ultimately, satisfactory estimates will require the integration of productivity measurement with accounts for income, saving, and wealth. Productivity measures of this type are available for the United States for the period 1929–67,[4] but much further work remains to be done in refining and extending these estimates.

Section 7 summarizes the results of these revisions, compares them with our original estimates, reviews Denison's objections to them, and explores some of the remaining unresolved issues. Our original conclusions are changed somewhat, primarily as the result of the reduction in the magnitude and scope of the relative utilization adjustment. The resulting estimates of growth in total factor productivity are closer to Denison's estimates than our original ones, but still significantly lower. Our revised estimates meet, we believe, all of Denison's valid objections to our original procedures. We have preserved, however, the major conclusion of our original paper: Growth in total input is a major rather than a minor source in the growth of national output. The estimated residual change in total factor productivity is smaller than asserted by other investigators but not so small as was implied by our original estimates. This requires a revision of the implication of our original paper that all of output growth could be accounted for by a corrected version of total input within the conventions of national income measurement. This does not seem to be the case.

Further progress in explaining productivity change will require allowing the rates of return to differ among different types of investment and among industries and not only among legal forms of organization. Returns to labor of comparable quality may also differ by age, race, sex, or occupation and these differences should be reflected in the measurement of labor input. Finally, a more detailed investigation of possible contributions to growth associated with externalities in the process of research and educational activities would be worthwhile. It is still our belief that the correct research strategy in this area is to refine and extend the accounts so as to minimize the contribution of the unexplained residual.

2. Measurement of Output

2.1 Introduction

We define the value of output and factor input from the point of view of the producer. For each sector of the economy we measure revenue as proceeds to the sector and outlay as expenditures of the sector. The value of output is net of taxes on output while the value of input is gross of taxes on input. The resulting concept of gross value added is intermediate between gross product at market prices, which is the concept of output employed in our earlier study, and gross product at factor cost.

For any concept of gross product the fundamental accounting identity for productivity measurement is that the value of output is equal to the value of input. Denoting the price of aggregate output by q, the quantity by Y, and the price and quantity of aggregate input input p and X, we may represent this identity in the form:

$$qY=pX.$$

In measuring total factor productivity we confine our attention to the private domestic economy. In the U.S. national income and product accounts the value of government services is equal to the value of labor services by definition.[5] The services of capital input in the government sector are ignored, so that product accounts for private and government sectors are not comparable. For the rest of the world sector investment is not included in investment goods output, as defined below, so that factor input accounts for domestic and foreign sectors are not comparable.

In the U.S. national income and product accounts the services of owner-occupied housing and structures utilized by nonprofit institutions are included in the product of the private sector. The value of the flow of services is imputed from data on rental values of comparable structures. Capital services from consumers' durables and producers' durables used by nonprofit institutions are not treated symmetrically with services from owner-occupied housing and institutional structures. Purchases of consumers' durables are included in personal consumption expenditures and purchases of producers' durables by nonprofit institutions are included in private investment, but the flow of capital services from this equipment is not included in the value of private product.

We treat the services of owner-utilized consumers' durables symmetrically with the services of owner-occupied housing and the services of producers' durables utilized by nonprofit institutions symmetrically with those of structures occupied by these institutions. Purchases of new consumers' durables and purchases of producers' durables by nonprofit institutions are transferred from personal consumption expenditures to private investment, leaving the value of total

Table 1.—Production Account, Gross Private Domestic Product and Factor Outlay, United States, 1958 (Current Prices) [a]

[Billions of dollars]

Line	Product	Total
1	Private gross national product (table 1.7)	$405.2
2	− Income originating in government enterprises (table 1.13)	4.8
3	− Rest of the world gross national product (table 1.7)	2.0
4	+ Services of consumers' durables (our imputation)	39.6
5	+ Services of durables held by institutions (our imputation)	.3
6	− Federal indirect business tax and nontax accruals (table 3.1)	11.5
7	+ Capital stock tax (table 3.1, footnote 2)	......
8	− State and local indirect business tax and nontax accruals (table 3.3)	27.0
9	+ Motor vehicle licenses (table 3.3)	.5
10	+ Property taxes (table 3.3)	13.3
11	+ Other taxes (table 3.3)	2.9
12	+ Subsidies less current surplus of Federal government enterprises (table 3.1)	2.7
13	− Current surplus of state and local government enterprises (table 3.3)	1.8
14	= Gross private domestic product	418.2
	Factor outlay	
1	Capital consumption allowances (table 1.9)	38.9
2	+ Business transfer payments (table 1.9)	1.6
3	+ Statistical discrepancy (table 1.9)	1.6
4	+ Services of consumers' durables (our imputation)	39.0
5	+ Services of durables held by institutions (our imputation)	.3
6	+ Certain indirect business taxes (product account above, 9 + 10 + 11)	17.4
7	+ Income originating in business (table 1.13)	312.2
8	− Income originating in government enterprises (table 1.13)	4.8
9	+ Income originating in households and institutions (table 1.13)	11.4
10	= Gross private domestic factor outlay	418.2

[a] All table references are to *The National Income and Product Accounts of the United States, 1929–1965* [66].

product unaffected. We impute the value of services of consumers' durables and producers' durables owned by institutions from rental values implied by the imputed service flow for owner-occupied housing and institutional structures. We add the resulting service flow to the product of the private sector, increasing the value of the total product. The values of gross private domestic product and factor outlay for the year 1958 are presented in table 1.

2.2 *Consumption, investment, labor, and capital*

In measuring total factor productivity we find it useful to divide total product between consumption and investment goods and total factor outlay between capital and labor services. In the U.S. national income and product accounts total output is divided among durables and structures output (which we denote investment goods output) and nondurables and services output (which we denote consumption goods output). Our definition of services output includes the services of consumers' durables and institutional durables along with the services output included in the U.S. accounts.

The value of private domestic factor outlay includes labor compensation of employees in private enterprises and in private households and nonprofit institutions, plus the labor compensation of self-employed persons.[6] In measuring labor compensation of the self-employed we assume for each sector that average labor compensation of proprietors and unpaid family workers is equal to the average labor compensation of full-time equivalent employees in the same sector. Our estimates of nonfarm proprietors and employees are those of the Office of Business Economics. Our estimates of unpaid family workers are those of Kendrick, allocated among sectors in proportion to the number of proprietors in each sector.[7] Our estimates of persons engaged in the farm sector are from Kendrick.

All outlay on factors of production not allocated to labor is allocated to capital. Outlay on capital services includes property income of the self-employed; profits, rentals, and interest; capital consumption allowances; business transfer payments; the statistical discrepancy; indirect business taxes that are part of the outlay on productive factors, such as motor vehicle licenses, property taxes, and other taxes; and the imputed value of the services of consumers' durables and producers' durables utilized by institutions.[8] Gross private domestic product and factor outlay in current prices for 1950–62 are given in table 2. Total product is divided between gross private domestic investment and gross private domestic consumption. Total factor outlay is divided between labor compensation and property compensation.

Table 2.—Gross Private Domestic Product and Factor Outlay, 1950–62 (Current Prices)

(Billions of dollars)

Year	Gross private domestic product	Investment goods product	Consumption goods product	Labor compensation	Property compensation
1950	269.0	91.2	177.8	156.3	112.7
1951	307.2	106.2	200.0	177.4	129.8
1952	323.0	108.2	214.7	188.0	134.0
1953	340.1	115.3	225.0	202.7	137.4
1954	343.0	110.0	233.0	200.8	142.1
1955	374.6	128.6	246.0	216.5	158.1
1956	396.3	136.3	260.0	234.0	163.3
1957	415.0	140.0	274.9	246.0	169.0
1958	418.2	130.4	287.8	245.1	173.1
1959	453.2	146.8	306.4	265.4	187.8
1960	472.3	148.8	323.5	278.7	193.6
1961	487.0	147.4	339.5	284.7	202.3
1962	523.8	163.8	359.8	302.6	220.7

2.3. *Price and quantity of output*

We turn next to the measurement of real product. Product is allocated between consumption and investment goods. Consumption goods include nondurable goods and services and investment goods include durable goods and structures. We construct quantity index numbers of output for these two types of output from data for the corresponding components of gross national product in constant prices. The product of the rest of the world and government sectors is composed entirely of services. The price index for the product of each of these sectors is assumed to be the same as for services as a whole. Quantity index numbers for the services of consumers' durables and institutional durables are constructed as part of our imputation of the value of these services. The value of output from the point of view of the producing sector excludes certain indirect business taxes less subsidies. The price of output is implicit in the value of output and the quantity index of output described above. Price and quantity indexes for gross private domestic product are presented in table 3.

Table 3.—Gross Private Domestic Product, 1950–62 (Constant Prices of 1958)

Year	Gross private domestic product, quantity index (billions of 1958 dollars)	Gross private domestic product, price index (1958=1.000)	Consumption goods product, quantity index (billions of 1958 dollars)	Consumption goods product, price index (1958=1.000)	Investment goods product, quantity index (billions of 1958 dollars)	Investment goods product, price index (1958=1.000)	Relative share of investment goods product (percent)
1950	328.8	0.818	214.786	0.823	113.904	0.801	0.339
1951	351.3	0.874	228.303	0.880	122.024	0.864	0.346
1952	360.3	0.896	237.311	0.905	122.062	0.880	0.336
1953	378.8	0.906	247.610	0.909	131.168	0.879	0.330
1954	375.7	0.913	250.310	0.927	125.151	0.885	0.323
1955	406.6	0.921	262.751	0.938	143.861	0.894	0.343
1956	416.2	0.952	272.947	0.966	143.281	0.948	0.341
1957	422.6	0.982	280.975	0.978	141.671	0.986	0.337
1958	418.2	1.000	287.791	1.000	130.419	1.000	0.312
1959	445.5	1.017	300.561	1.020	144.978	1.013	0.324
1960	457.1	1.033	309.884	1.044	147.281	1.010	0.315
1961	466.1	1.045	320.175	1.060	145.783	1.012	0.303
1962	495.1	1.067	334.790	1.075	160.428	1.019	0.313

3. Measurement of Capital Input

3.1. Introduction

Our original estimates of capital input distinguished among five categories of capital input—land, residential and nonresidential structures, equipment, and inventories. Our approach has now been extended by Christensen and Jorgenson [19, 20] to 16 classes of assets, separating inventories into farm and nonfarm categories and adding consumers' durables to the other asset categories. Each asset category has been allocated among corporate, noncorporate, household, and institutional sectors.[9] This classification of assets permits a much more satisfactory treatment of the taxation of income from capital services. The original classification of assets was not sufficiently detailed to permit a fully satisfactory treatment of the tax structure. The relative proportions of capital stock by asset class for each sector for 1958 are given in table 4.

We have divided assets among sectors of the private domestic economy that differ in the tax treatment of property income. Households and institutions utilize the services of consumers' and institutional durables, owner-occupied dwellings, institutional structures, and land. No direct taxes are levied on this property income, but part of the income is taxed indirectly through property taxes. To incorporate property taxes into the capital service price, we add the rate of property taxation to the rate of return, the rate of replacement, and the rate of capital loss. Noncorporate business utilizes services from residential and nonresidential structures, producers' durable equipment, nonfarm and farm inventories, and land held by that sector. This property income is taxed directly through the personal income tax and indirectly through property taxes. We measure the noncorporate rate of return before personal income taxes.

Corporations utilize services from residential and nonresidential structures, producers' durable equipment, nonfarm inventories, and land. We employ the capital service prices for corporate capital input developed by Hall and Jorgenson [52, 53] for depreciable assets, modified to include indirect business taxes,[10] including property taxes. Corporate property income is taxed directly through the corporation income tax and through the personal income tax and indirectly through property taxes. We measure the corporate rate of return before personal income taxes but after corporation income taxes.

Table 4.—Relative Proportions of Capital Stock by Sector, 1958

Asset class	Sector: Corporate business	Noncorporate business	Households and institutions
Consumers' durables	0	0	1.00
Nonresidential structures	.72	.18	.10
Producers' durables	.68	.31	.01
Residential structures	.08	.07	.85
Nonfarm inventories	.82	.18	0
Farm inventories	0	1.00	0
Land	.19	.50	.31

3.2. Perpetual inventory method

The starting point for a revised index of real capital input is the estimation of capital stock by the perpetual inventory method. In discrete time the perpetual inventory method may be represented in the form:

$$K_{it} = I_{it} + (1 - \mu_i) K_{i,\,t-1}$$

where K_{it} is the end-of-period capital stock, I_{it} the quantity of investment occurring in the period, and μ_i the rate of replacement, all for the ith investment good. For each type of investment good we follow these steps in estimating capital stock by the perpetual inventory method: (1) a benchmark is obtained, (2) the investment series in current prices from the U.S. national accounts is deflated to obtain a real investment series, (3) a rate of replacement is chosen, and (4) the stock series is computed using the perpetual inventory method described above. Benchmarks for 1958, rates of replacement, and price indexes for each capital good are given in table 5. Price indexes for each asset class for 1950–62 are given in table 6.

Our method for separating price and quantity components of a flow of capital services is based on the corres-

Table 5.—Benchmarks, Rates of Replacement, and Price Indexes Employed in Estimating Capital

Asset class	1958 benchmark (billions of 1958 dollars)	Replacement rate	Deflator (sources given below)
Consumers' durables	116.2	0.200	Implicit deflator, national product accounts.[a]
Nonresidential structures	136.1	.056	Constant cost 2 deflator.[b]
Producers' durables	123.4	.138	Implicit deflator, national product accounts.[a]
Residential structures	336.2	.039	Constant cost 2 deflator.[b]
Nonfarm inventories	80.3		Investment: Implicit deflator, national product accounts.[c] Assets: BLS wholesale price index, goods other than farm products and food.[d]
Farm inventories	24.5		Investment: Implicit deflator, national product accounts.[c] Assets: BLS wholesale price index, farm products.[d]
Land	322.2		Goldsmith.[e]

a NIP [86], table 8.1.
b *Capital Stock Study* [49].
c NIP [86], tables 1.1 and 1.3.
d BLS [15].
e Goldsmith [35], tables A-5 and A-6.

pondence between asset prices and service prices implied by the equality between the value of an asset and the the value of its services. This correspondence is the counterpart in price estimation to the relationship between investment and changes in capital stock used in estimation of national wealth by the perpetual inventory method. Data on asset prices, rates of replacement, and investment are required for perpetual inventory estimates of capital stock.[11] Our method for separation of property compensation between the price of capital services and its quantity requires the same data as the perpetual inventory method for measurement of capital stock, together with data on property income and the tax structure. Data on property compensation by legal form of organization, such as those presented in the U.S. national income and product accounts, are essential for incorporating the effects of the tax structure. This straightforward extension of the perpetual inventory method makes it possible to allocate property income among different classes of assets.

To make the correspondence between asset prices and service prices explicit we must specify the relationship between the quantity of an asset acquired at one date and the quantity of the service flow of the asset at future dates. In our perpetual inventory estimates of the stock of assets, we have assumed that the service flow from the ith investment good declines geometrically over time,

$$1,\ (1-\mu_i),\ (1-\mu_i)^2\ \ldots\ .$$

To infer the capital service price from the sequence of asset prices, we first write the asset price as the discounted value of future services,

$$q_{it}^A=\sum_{\tau=t}^{\infty}\prod_{s=t+1}^{\tau+1}\frac{1}{1+r_s}p_{i,\tau+1}^S(1-\mu_i)^{\tau-t}$$

where r_s is the rate of return in period s, q_{it}^A is the price of the ith investment good at time t and p_{it}^S is service price of the ith investment good. Solving for the service price, we obtain

$$p_{it}^S=q_{i,t-1}^A r_t+q_{it}^A\mu_i-(q_{i,t}^A-q_{i,t-1}^A).$$

Given the sequence of asset prices $\{q_{it}^A\}$, the rate of replacement μ_i, and the rate of return r_t, we obtain the perpetual inventory estimate of the service price of the ith investment good p_{it}^S.

The correspondence between asset prices and service prices implied by the perpetual inventory method is precisely the same correspondence that underlies the measurement of net capital stock. As Denison points out, ". . . net stock measures . . . the discounted value of future capital services."[12] The measurement of net capital stock is well established in social accounting practice; our formula for the perpetual inventory estimate of the capital service price is an immediate implication of accounting methods for net capital stock. This formula may be generalized to alternative assumptions about the time pattern of the service flow associated with an asset. The formula developed by Haavelmo [50] for a constant service flow over the lifetime of the asset has been suggested as a means of aggregating capital services by Johansen and Sorsveen [56]. Arrow [4] has provided formulas for the service price for an arbitrary sequence of replacements. In Arrow's formula the rate of replacement μ_i, which we have assumed constant for each class of assets, is replaced by a weighted average of rates of replacement over the lifetime of the asset.

3.3. *Price of investment goods*

The price indexes used by Christensen and Jorgenson in constructing the capital stock series differ from our original ones in using the national income implicit deflator for producers' durable equipment and the WPI as the deflator of the *stock* of inventories. There is enough evidence that the various official capital deflator series are biased upward during this period for us to be unwilling to concede that our original attempt to substitute something else (the CPI durables index) for the official equipment investment deflator was an error. While this is not the place to go into great detail, there is ample evidence that components of the WPI, which in turn are a major source of deflators for the producers' durables investment, are (or at least have been) rather poor measures of price change. The WPI is based almost entirely on company and trade papers and association reports. Moreover, for a variety of reasons, it has had much less resources devoted to it relative to the CPI. All this has combined to produce what we believe to be a significant upward drift in components of this index during the post-World War II period.[13]

Table 6.—Price Indexes by Class of Asset, 1950–62

[1958=1.000]

Year	Consumers' durables	Structures, nonresidential and residential	Producers' durables	Investment, nonfarm inventories	Assets, nonfarm inventories	Investment, farm inventories	Assets, farm inventories	Land
1950	0.878	0.763	0.752	0.800	0.833	1.000	1.027	0.706
1951	.942	.836	.800	.919	.920	1.260	1.195	.760
1952	.954	.881	.822	.840	.899	1.429	1.127	.735
1953	.943	.885	.845	.784	.908	1.500	1.022	.796
1954	.920	.887	.840	.804	.908	1.300	1.005	.811
1955	.919	.902	.849	.917	.929	1.250	.945	.840
1956	.940	.959	.918	.944	.970	.667	.942	.887
1957	.964	1.001	.975	1.142	.997	1.000	.905	.981
1958	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1959	1.014	1.006	1.020	1.000	1.018	(a)	.998	1.069
1960	1.009	1.006	1.022	1.031	1.015	1.000	.935	1.148
1961	1.006	1.006	1.021	.944	1.013	1.500	.924	1.322
1962	1.008	1.024	1.028	1.019	1.012	1.000	.948	1.306

a Investment in constant prices is zero.

Our example of consumer durables was not intended to claim that the particular items were representative of most of the producers' durables but rather that such a comparison allowed one to detect the magnitude of the drift in the WPI which was due to the particular way in which its data were collected. The difference between the movement of prices for these identical items in the two index sources was interpreted not as property of the particular items, but as an estimate of the bias introduced by the basic procedure used in collecting the wholesale price data. The latter, we assumed, was generalizable to most of the other WPI items.

Actually, there is quite a bit more evidence on this point than was alluded to in our original paper and some of it is presented in table 7. The first line recapitulates the CPI–WPI identical durables comparison. The other comparisons can be divided into three groups: (1) transaction price data (circuit breakers and power transformers from the Dean-DePodwin study and tubes and batteries prices from Flueck's staff report); (2) more detailed attention to quality change and/or more analysis of the changing specifications of the priced items, sometimes via regression techniques (Dean-DePodwin and Census on steam generators, Barzel on electric equipment, the Association of American Railroads on railroad equipment prices, and Fettig on tractor prices); and (3) wider coverage and transaction pricing (Census unit values data).

The last, Census based, set of data (summarized in table 8) is particularly interesting since one might have expected that unit values would themselves be upward biased due to the secular shift to more elaborate, higher "quality" models. In fact, they and all the other additional comparisons point strongly to the existence of an upward bias in the comparable WPI components, at least in the recent past. Our implied estimate of this upward drift of 1.4 percent per year between 1950 and 1962 is quite consistent with the new evidence presented in this table. While it is not used in the productivity computations we borrow from Christensen and Jorgenson we are willing to stand by this part of our original estimates.[14]

Our substitution of the new OBE "constant cost 2" construction deflator for the comparable implicit GNP de-

Table 7.—Evidence on Drift in Components of WPI

Item	Reference	Period	Approximate drift in percent per year [a]
Identical consumer durables [b] (10 items)	CPI	1947-49-1958	1.9
Circuit breakers	Dean-DePodwin [c]	1954-59	4.0
Power transformers	Dean-DePodwin	1954-59	.7
Power transformers	Census [d]	1954-63	1.2
Steam generators	Dean-DePodwin	1954-60	1.9
Steam generators	Census [e]	1954-63	0.4
Electric equipment	Dean-DePodwin	1954-59	1.2
Electric equipment	Census [d]	1954-63	1.9
Electric equipment	Barzel [f]	1949-59	4.4
Railroad equipment	Association of American Railroads [g]	1961-67	.6
Tractors	Fettig [h]	1950-62	.6
Tubes, automobile	Flueck [i]	1955-60	1.4
Batteries, vehicle	Flueck [i]	1949-60	6.3
Storage batteries	Census [d]	1954-63	2.9
Plumbing and heating	Census [d]	1954-63	1.2
Oil burners	Census [d]	1954-63	2.8
Warm air furnaces	Census [d]	1954-63	1.1
Metal doors	Census [d]	1954-63	.7
Bolts and nuts	Census [d]	1954-63	2.3
Internal combustion engines	Census [d]	1954-63	1.8
Elevators and escalators	Census [d]	1954-63	1.1
Pumps and compressors	Census [d]	1954-63	3.0
Integrating instruments	Census [d]	1954-62	3.1
Electric welding	Census [d]	1954-63	−1.1
Electric lamps	Census [d]	1954-63	1.1
Trucks	Census [d]	1954-63	.3

[a] Last column is the average change, over the specified period, in the particular WPI component relative to the estimated price change over the same period in the alternative source.

[b] The following items were compared for this period: automobiles, tires, radios, refrigerators, sewing machines, ranges, washing machines, vacuum cleaners, toasters, and furniture.

[c] Dean and DePodwin [28] and an unpublished appendix to the original General Electric version.

[d] 1963 *Census of Manufactures* [8], Vol. IV, *Indexes of Production*, Appendix A.

[e] Census unit values, adjusted for capacity and horsepower differences, 1963 Census of Manufactures [8], Vol. IV, *Indexes of Production*, Appendix A.

[f] Barzel [6]. Indexes in table 3 holding size constant are essentially flat throughout this period. A similar story is also told by the indexes in table 6, where size is taken into account.

[g] Joint Equipment Committee Report [58] shows no significant increase in the "cost" of locomotives and freight and passenger cars during this period.

[h] Fettig [29], table 8, p. 609.

[i] J. Flueck [32].

Table 8.—A Comparison of OBE Producers' Durables Investment Deflators With Census Unit Value Indexes, 1962 (1954=100)

Category	Percent direct [a] coverage by data from Census	Census [a] (cross weights)	OBE [b]	Drift in percent per year
Furniture and fixtures	42	110.8	119.1	0.8
Fabricated metal products	34	117.3	121.7	.4
Engines and turbines	54	93.3	134.7	4.2
Construction machinery	20	126.2	132.0	.5
Metalworking machinery	42	122.9	137.2	1.2
Special industry machinery	20	119.3	136.7	1.7
General industry machinery [c]	15	118.0	131.4	1.3
Service industry machinery	27	83.8	100.9	2.3
Electric machinery	27	98.7	112.0	1.4
Trucks and buses [d]	91	118.0	122.6	.4
Ships and boats	27	100.1	116.6	1.7
Railroad equipment	45	132.1	128.4	−.3

[a] 1963 *Census of Manufactures* [8], Vol. IV, *Indexes of Production*, Appendix A.

[b] NIP [60], Table 8.8. For tractors, agricultural machinery, mining and oil field machinery, office equipment, passenger cars, aircraft, and instruments Census unit values are based on less than 15 percent coverage from Census sources. For a comparison of tractor price indexes see table 7.

[c] OBE definition includes also materials handling machinery.

[d] Four separate Census categories aggregated using 1963 shipments as weights.

flator component is not ideal and could be improved on. The "constant cost 2" deflator is an average, implicitly, of the Bureau of Public Roads highway structures, the Bureau of Reclamation pumping and power plant indexes, and the A.T. & T. and Turner construction cost indexes. The latter two are basically input price rather than output price indexes with some feeble adjustment for productivity changes.[15] The Bureau of Reclamation indexes are hard to interpret and seem to be based, to a large extent, on list prices of raw materials. A recent study by Gordon [40] indicates that the constant cost 2 index may also be biased upward to an unknown degree.[16] It is likely, therefore, that if a more accurate construction price index were used it would imply a higher rate of growth in the structures component of capital input than was estimated in our original paper and is also used in this one. In short, more remains to be done in this area but we believe that our original procedures were on the right track. The estimates we borrow from Christensen and Jorgenson are conservative in their choice of investment deflators.

3.4. Price of capital services

3.4.1. Introduction.—The second step in the construction of a revised index of real capital input is to divide the value of capital services between price and quantity with price corresponding to the rental rate and quantity as the amount of capital services utilized. This division is precisely analogous to the separation of the value of labor services between a wage rate and the quantity of labor services. For property with an active rental market the separation may be carried out by means of market data on rental rates and corresponding data on the employment of capital. This method may be extended from rental property to property utilized by its owners if market rental values reflect the implicit rentals paid by owners for the use of their property. An imputation of this type is employed in the U.S. national income and product accounts in the measurement of services of owner-occupied housing.[17] A precisely analogous imputation occurs in measuring labor services of the self-employed. Market wage rates are used as a basis for imputing the implicit wage rates paid to the self-employed.[18] The main obstacle to application of this method to capital services on a comprehensive basis is the lack of sufficient data on market rental values.

To impute capital service prices we must estimate rates of return for corporate business, noncorporate business, and households and institutions.[19] As an accounting identity for each sector the value of all capital services is equal to total property income. We measure the value of capital services for each sector before either corporate or personal income taxes, but we measure the rate of return after corporate income taxes and before personal income taxes. In each sector asset prices and stocks, rates of replacement, and parameters describing the tax structure are given as data. The rate of return for each sector is chosen at each point of time so as to maintain the identity between property income and the value of all capital services in the sector.

Each capital service flow may be expressed as the sum of four terms, depending on the rate of return, the rate of replacement, the rate of capital losses accrued, and the rate of property taxation. Since property taxes are deducted from corporate income in determining corporate profits for tax purposes, the component of each capital service flow corresponding to property taxes is simply added to the other components. Similarly, the property tax component of each capital service flow for the noncorporate and household sector is simply added to the rest. Accordingly, our first step in estimating rates of return for the three sectors is to deduct all property taxes from the value of property compensation.

3.4.2. Household sector.—Our measurement of the flow of capital services for the household sector is independent of the measurement of flows of capital services for the corporate and noncorporate sectors. The value of services of owner-occupied farm and nonfarm dwellings is the space-rental value of dwellings less associated purchases of goods and services. We assume that the proportion of purchases is the same for farm as for nonfarm dwellings. The effective tax rate is the ratio of taxes as a component of total space-rental value to the asset value of owner-occupied dwellings, including both structures and land. The value of services of institutional structures is the space-rental value of institutional buildings. To estimate the rate of return we divide the space-rental values of owner-occupied dwellings and institutional buildings, less associated purchases of goods and services for dwellings, less current replacement values, accrued capital losses, and taxes as a component of total space-rental value for dwellings by the current asset value of owner-occupied dwellings and institutional structures, including land.

Our measurement of the output of the producing sector differs from that of the U.S. national income and product accounts in the treatment of consumers' and institutional durables. We assign personal consumption expenditures on durables to gross investment rather that to current consumption. We then add the service flow from consumers' and institutional durables to the value of output and the value of capital input. The value of each service flow is the product of the service price given above and the corresponding service quantity. The values of these service flows enter the product and factor outlay accounts given in table 1. We assume that the rate of return on durables is the same as that on structures for the household sector. The effective tax rate on consumers' durables is the ratio of the following State and local personal taxes—motor vehicle licenses, property taxes, and other taxes—plus Federal automobile use taxes to the current asset value of consumers' durables. The effective property tax rates on household property and the rate of return for the household sector are presented in table 9.

3.4.3. Noncorporate sector.—In measuring the rate of return for the noncorporate business sector we first estimate the effective tax rate on noncorporate property. We deduct property taxes on owner-occupied residential real estate from State and local business property taxes to obtain State and local property taxes for corporate and noncorporate sectors.[20] We allocate business

Table 9.—Effective Tax Rates and Rates of Return, Household and Noncorporate Sectors, 1950–62 (Annual Rates)

Year	Effective tax rate on owner-occupied residential real estate	Effective tax rate on owner-utilized consumers' durables	Effective tax rate on noncorporate property	Rate of return, household sector	Rate of return, noncorporate sector
1950	0.009	0.008	0.018	0.063	0.178
1951	.008	.007	.017	.106	.214
1952	.009	.007	.018	.082	.121
1953	.009	.007	.019	.080	.089
1954	.010	.007	.019	.032	.108
1955	.011	.007	.020	.040	.114
1956	.012	.007	.010	.068	.127
1957	.012	.007	.020	.069	.127
1958	.013	.007	.020	.036	.116
1959	.013	.007	.020	.047	.103
1960	.014	.008	.021	.048	.098
1961	.016	.008	.022	.047	.089
1962	.015	.009	.022	.058	.111

motor vehicle licenses between corporate and noncorporate sectors in proportion to the value of producers' durables in each sector; similarly, we allocate other State and local business taxes and Federal capital stock taxes in proportion to the value of all assets in each sector. The effective tax rate on noncorporate property is the ratio of the sum of property taxes, motor vehicle licenses, and other business taxes allocated to the noncorporate sector to the value of all assets held by the sector, including producers' durables, residential and nonresidential structures, inventories, and land.

The value of capital services for the noncorporate sector is the sum of income originating in business, other than income originating in corporate business, income originating in government enterprises, and interest and net rent of owner-occupied dwellings and institutional structures, less labor compensation in the noncorporate sector, including imputed labor compensation of proprietors and unpaid family workers, plus noncorporate capital consumption allowances, less capital consumption allowances of owner-occupied dwellings and institutional structures, and plus indirect business taxes allocated to the noncorporate sector, as outlined above. We also allocate the statistical discrepancy to noncorporate property income.[21] To obtain our estimate of the noncorporate rate of return we deduct property taxes and the current value of replacement, add accrued capital gains on noncorporate assets, and divide by the value of noncorporate assets. The effective tax rate on noncorporate property and the rate of return in the noncorporate sector are given in table 9.

3.4.4. Corporate sector.—In measuring the rate of return for corporate business we begin by estimating the effective tax rate on corporate property. We add State and local business property taxes, business motor vehicle licenses, other business taxes, and Federal capital stock taxes for the corporate sector to obtain total property taxes. The effective tax rate on corporate property is the ratio of these taxes to the value of all assets held by the corporate sector, including producers' durables, residential and nonresidential structures, inventories, and land. We measure corporate property income less property taxes as income originating in corporate business, less compensation of employees, plus corporate capital consumption allowances, plus business transfer payments.[22] The value of corporate capital input, which is equal to corporate property income, depends on the effective corporate income tax rate, the rate of return in the corporate sector, the investment tax credit, and the present values of depreciation deductions for nonresidential structures, producers' durables, and residential structures.

Corporate income taxes less the investment tax credit are equal to the effective tax rate applied to corporate property income, less property taxes and less deductions for capital consumption, expressed as proportions of current capital service flows after taxes.

Our estimate of the effective rate of the investment tax credit is based on estimates of investment tax credit for corporations by the Office of Business Economics. The effective rate is defined as the amount of the investment tax credit divided by gross private domestic investment in producers' durables by corporations. We assume that the effective rate of the investment tax credit is the same for corporations and for noncorporate business. Although the nominal rate of the investment tax credit is 7 percent, certain limitations on its applicability reduce the effective rate considerably below this level.[23]

The present values of depreciation deductions on new investment depend on depreciation formulas allowable for tax purposes, the lifetimes of assets used in calculating depreciation, and the rate of return.[24] A reasonable approximation to depreciation practice is provided by the assumption that the straight-line depreciation formula was the only one permitted for assets acquired up to 1953 and that an accelerated depreciation formula, sum of the years' digits, was employed for assets acquired during the period 1954–62.[25] Given depreciation formulas and lifetimes for tax purposes, calculation of present values of depreciation deductions requires an estimate of the rate of return for discounting these deductions. We assume that this rate of return was constant at 10 percent.[26] Substituting the present values of depreciation deductions into expressions for capital service prices we reduce the unknown variables to two, the effective corporate tax rate and the rate of return in the corporate sector. Corresponding to these two unknowns, we have two equations. The first relates corporate property income and the sum of values of the individual capital services. The second relates corporate income taxes and the effective tax rate on corporate income, applied to the corporate income tax base, less the investment tax credit. We measure corporate income taxes as Federal and State corporate profits tax liability. Since the two equations are independent, we may solve for values of the effective corporate tax rate and the corporate rate of return in each time

Table 10.—Tax Structure and Rate of Return, Corporate Sector, 1950–62 (Proportions and Annual Rates)

Year	Effective tax rate on corporate property	Effective rate of investment tax credit	Statutory rate of investment tax credit	Effective tax rate on corporate income	Statutory tax rate on corporate income	Present value of depreciation deductions, nonresidential structures	Present value of depreciation deductions, producers' durables	Present value of depreciation deductions, residential structures	Rate of return, corporate sector
1950	0.016	0	0	0.451	0.420	0.273	0.397	0.262	0.107
1951	.014	0	0	.521	.509	.273	.397	.262	.147
1952	.014	0	0	.482	.520	.273	.397	.262	.079
1953	.015	0	0	.477	.520	.273	.397	.262	.088
1954	.015	0	0	.475	.520	.413	.543	.400	.081
1955	.016	0	0	.478	.520	.425	.580	.419	.092
1956	.016	0	0	.477	.520	.438	.579	.426	.124
1957	.016	0	0	.488	.520	.453	.596	.439	.106
1958	.016	0	0	.455	.520	.460	.614	.455	.069
1959	.016	0	0	.494	.520	.456	.622	.473	.079
1960	.016	0	0	.487	.520	.456	.622	.473	.069
1961	.017	0	0	.479	.520	.456	.628	.473	.062
1962	.017	.037	.070	.480	.520	.456	.622	.473	.085

period. Variables describing the corporate tax structure and the corporate rate of return for 1950–62 are presented in table 10.

3.5. Price and quantity of capital services

In separating the value of capital input into price and quantity components our basic accounting identity is that for each sector the value of all capital services or property compensation is equal to the sum of the values of the individual capital services. In constructing Divisia index numbers of capital service price and quantity we combine service prices and quantities by class of asset for all sectors. Finally, we combine service price and quantity indexes by class of asset into an overall capital service price index and potential service quantity index, again as Divisia index numbers. We note that the overall service price and quantity indexes include capital services from assets held by households and institutions as well as by businesses. Price and quantity indexes of potential capital services for corporate, noncorporate, and household sectors for 1950–62 are given in table 11.

4. Relative Utilization of Capital

4.1. Introduction

It has been common to assume that one may be able to approximate the unemployment of capital by the unemployment of labor. Solow [71] assumed that there is a proportionality relationship between these concepts (and his capital measure included land and buildings, too!) while Okun [67] suggested a nonlinear relationship between the two. It appeared to us that the unemployment of capital can be better approximated by the "unemployment" of one kind of capital (power-driven equipment), implicitly assuming a proportionality relationship between this type of capital and other capital, than by the assumption of proportionality between the employment of all labor and of all capital.

It is our assumption, for which we have no explicit evidence, that our measure of utilization measures not only the utilization of power-driven equipment but also the fraction of

Table 11.—Potential Gross Private Domestic Capital Input, 1950–62 (Constant Prices of 1958)

Year	Corporate capital input, quantity index (billions of 1958 dollars)	Corporate capital input, price index (1958=1.000)	Noncorporate capital input, quantity index (billions of 1958 dollars)	Noncorporate capital input, price index (1958=1.000)	Household capital input, quantity index (billions of 1958 dollars)	Household capital input, price index (1958=1.000)	Private domestic capital input, quantity index (billions of 1958 dollars)	Private domestic capital input, price index (1958=1.000)
1950	47.9	1.097	34.9	0.894	39.0	0.846	121.2	0.980
1951	49.9	1.193	36.6	1.029	43.8	.848	129.9	.949
1952	53.8	1.011	37.6	.986	46.6	.898	137.2	.977
1953	56.5	1.004	38.3	.959	48.7	.939	142.2	.967
1954	57.7	.970	38.9	.950	51.6	.906	147.9	.961
1955	59.0	1.141	39.5	.957	54.3	.969	152.8	1.037
1956	61.9	1.101	40.3	.884	58.7	1.011	160.7	1.101
1957	65.6	1.075	30.7	.909	61.6	1.008	167.5	1.009
1958	67.8	1.000	41.2	1.000	64.1	1.000	173.1	1.000
1959	68.7	1.154	41.5	.924	65.6	1.067	175.8	1.067
1960	70.9	1.119	42.2	.899	68.4	1.121	181.7	1.068
1961	73.4	1.110	42.8	.938	70.9	1.137	187.5	1.079
1962	75.2	1.211	43.2	1.025	73.0	1.171	191.7	1.161

calendar time that establishments or plants are in actual operation. That is, machine-hours per week are interpreted as a proxy for total hours per week operated by an establishment or industry. This, of course, is not an unambiguous concept, but it does explain why we were and still are willing to apply this estimated utilization rate not only to equipment but also to buildings. We are also willing, for lack of any better evidence, to extrapolate this to all industrial and agricultural equipment and structures and also to structures and equipment in the service industries. There is some scattered evidence that the hours operated per week by various retail establishments have increased in recent years.

4.2. Measurement of relative utilization

In measuring the change in utilization between 1945 and 1954 by the average estimated change in utilization (per annum) between 1939 and 1954, we overestimated the former. The estimates used in this paper (also taken from Christensen and Jorgenson) solve this problem by adding a cyclical adjustment to the previously computed secular one. The benchmark years are now used only to derive the ratio of installed horsepower to potential capital. This ratio is assumed to change slowly and is interpolated linearly between benchmarks. Installed horsepower is then estimated as the product of this ratio and our index of potential flow of (business) capital services. The ratio of electric power consumed by motors to this estimate of installed horsepower is our new measure of relative utilization. The resulting series grows at a significantly lower rate, 0.54 percent per year, during the 1950–62 period than the utilization index used in our original study (which rose at 10.6 percent per year).

Denison suggests that the weighting of utilization estimates for industry groups should be done by something other than the total horsepower of electric motors. Since we use it as a proxy for the utilization of all capital, the appropriate weights would be estimates of the value of capital services at the two-digit level. The closest we can come to it is to use weights based on the distribution of total fixed assets in 1962. Recomputing our estimates separately for each two-digit industry and then weighting them with these weights doesn't really change the numbers significantly (see table 12). If anything, it makes them slightly higher. The same is also true for mining during the 1954 to 1963 period (see table 13). The resulting weighted utilization index is still quite high and of the same order of magnitude as the manufacturing one (if allowance is made for the cyclical difference between 1963 and 1962). We conclude, therefore, that the unweighted figures we used are rather close to what the weighted figures would have been had we computed them.

Thus, except for the over-estimate of the rate of change of utilization from 1945 to 1954, our estimates appear to be reasonably good estimates of the

Table 12.—Relative Utilization of Electric Motors, U.S. Manufacturing, 1962

Industry [a]	Indexes, 1954=1.000: Horsepower of electric motors [b] (1)	Indexes, 1954=1.000: Total electricity consumption [c] (2)	Indexes, 1954=1.000: Utilization [d] (3)	Total fixed assets weight [e] (4)
20	1.420	1.639	1.084	0.166
21	1.446	1.794	1.241	.004
22	1.155	1.229	1.064	.036
24	1.543	1.289	.835	.023
25	1.247	1.438	1.153	.008
26	1.616	1.624	1.005	.079
27	1.833	2.255	1.201	.034
28	1.542	1.760	1.140	.122
29	1.537	1.766	1.149	.069
30	1.644	1.670	1.016	.024
31	1.158	1.335	1.153	.004
32	1.379	1.447	.944	.055
33	1.289	1.364	1.061	.165
34	1.288	1.458	1.134	.049
35 and 36	1.344	1.713	1.275	.119
37	1.173	1.505	1.283	.076
38	1.234	2.187	1.773	.012
39 and 19	1.082	1.834	1.235	.014
Total [f]	1.398	1.567	1.111	
Total weighted [g]			1.115	

[a] "Two digit" manufacturing industries. Industry 23 apparel, excluded because no horsepower figures were asked for in 1954.
[b] Horsepower of electric motors from 1963 *Census of Manufactures* [7], "Power Equipment in Manufacturing Industries as of December 31, 1962", MC 63 (1)—6, table 2.
[c] Electricity, total purchased and generated minus sold, from 1963 *Census of Manufactures* [7], "Fuels and Electric Energy Consumed in Manufacturing Industries: 1962", MC 63 (1)—7, table 3.
[d] Utilization: column 2/column 1.
[e] 1962 fixed assets weights computed from 1964 *Annual Survey of Manufactures* [6], M 64 (AS)—6.
[f] Numbers differ from Table X in Jorgenson and Griliches [60], because no allowance could be made at the two-digit level for electricity consumption in nuclear energy installations. The comparable utilization index for total manufacturing allowing for this is 1.111.
[g] Σ (column 3×column 4)/0.987, where 0.987=Σ column 4.

Table 13.—Equipment Utilization Indexes, Mining Industries, 1963 (1954=100)

Industry	Horsepower of electric motors [a] (1)	Electricity consumption [b] (2)	Utilization index [c] (3)	Depreciable assets weights [d] (4)
Metal mining	111.3	175.0	157.2	0.246
Anthracite	42.4	51.7	122.0	[e] .014
Bituminous coal	92.4	134.6	136.3	[e] .184
Oil and gas	224.0	229.6	102.5	.432
Nonmetallic minerals	152.2	158.9	103.1	.174
Total mining	126.4	149.3	117.0	
Adjusted			[f] 127.6	
Weighted			[g] 120.7	

[a] 1963 Census of Mining [8], Chapter 7, table 1.
[b] 1963 Census of Mining [8], Chapter 6, table 1; purchased and used.
[c] Column 2/column 1.
[d] From U.S. Internal Revenue Service, *1962 Statistics of Income* [56]. *Corporation Income Tax Returns*, table 37, col. 4, p. 264.
[e] Total "coal mining" weight allocated on the basis of 1954 data for total capital given in Creamer [22], table B-11, p. 315.
[f] Adjusted for a small implied change in percentage of electric power used by electric motors (from 93.5 to 93.3) using the 1963 percentages given by Foss [33] and the 1954 and 1963 total electricity consumption as weights.
[g] Σ(column 3 x column 4).

Table 14.—Selected Utilization Measures

Year	Cotton broad woven goods: Average loom hours per loom in place [a]	Cotton-system spindle hours per spindle in place [b]	Manmade fiber broadwoven goods: Average loom hours per loom in place [a]
1947	5,042	5,074	5,220
1948	5,161	5,306	5,408
1949	4,680	4,433	4,991
1950	5,547	5,048	6,583
1951	5,276	5,838	5,045
1952	5,046	4,979	4,070
1953	5,579	5,518	5,240
1954	4,451	5,141	4,802
1955	5,998	5,601	5,326
1956	5,837	5,733	5,038
1957	5,425	5,612	5,403
1958	5,480	5,211	5,397
1959	6,114	5,853	5,718
1960	6,146	6,210	5,844
1961	6,020	5,830	5,717
1962	6,041	6,233	6,042
1963	6,124	6,074	6,105
1964	6,460	6,243	6,412
1965	6,741	6,480	6,518
Rates of growth, percent per year:			
1950–62	0.8	1.8	0.7
1947–65	1.6	1.4	1.7

[a] Computed from various issues of *Current Industrial Reports* [12], series M22T.1 and M22T.2. 1947–1963: Looms in place are averages of quarterly data as of the end of the quarter; 1964–64: Looms in place are averages of beginning and of year figures; 1965 for cotton broadwoven goods extrapolated on the basis of averages of monthly data on average hours per loom per week from the American Textile Manufacturers Institute [2], for manmade fibers based on looms in place at the end of 1964.

[b] Bureau of the Census, *Cotton Production and Distribution* [11], page 37. This is a more variable series, since the denominator is available only once during each year.

rate of utilization of electric motors in manufacturing. Similar estimates were presented for mining in table 13. An entirely different set of estimates, based on actual machine-hours worked for three textile subindustries, is presented in table 14. They, too, indicate an upward trend in utilization in the post-World War II period of about the same order of magnitude. Thus, there is something in these data. They are measuring something, at least as far as the utilization of electic motors in manufacturing and mining is concerned.

Given our data, it was an error on our part (and on the part of those who preceded us on this path) to adjust the residential housing, land, and inventories components by this measure of capacity utilization. Until better evidence comes along, however, we are willing to hazard the very strong assumption that the capacity utilization of all *business* equipment and structures may be approximated by our estimate of capacity utilization of power-driven equipment in manufacturing (and mining). Business equipment and structures account for about 46 percent of our total capital input. Applying this to the reduced rate of growth in utilization leads to a utilization adjustment on the order of 16 percent of our previous adjustment.

4.3. Actual and potential capital services

The index of relative utilization used in this paper is given in table 15. Since the value of the capital service flow as we have measured is independent of the rate of utilization, we define a price and quantity index of actual capital services as price and quantity indexes of potential capital services, divided and multiplied, respectively, by our index of relative utilization. Price and quantity indexes of actual capital services for corporate and noncorporate sectors and price and quantity indexes of actual capital services for the private domestic economy for 1950–62 are also presented in table 15.

To provide the basis for comparison of sources of growth of capital input with those for labor input, we present data on capital *stock*, potential service flow per unit of capital stock, and the relative utilization of capital in table 16. Capital stock is a Divisia index of capital stock for each class of asset—consumers' durables, nonresidential structures, producers' durables, residential structures, nonfarm inventories, farm inventories, and land. The potential service flow per unit of capital stock is the ratio of the quantity of potential gross private domestic capital input from table 11 to the index of capital stock. The relative utilization of *capital* is the ratio of the quantity of actual to potential gross private domestic capital input.

Table 15.—Actual Gross Private Domestic Capital Input, 1950–62 (Constant Prices of 1958)

Year	Corporate capital input, quantity index (billions of 1958 dollars)	Corporate capital input, price index (1958=1.000)	Noncorporate capital input, quantity index (billions of 1958 dollars)	Noncorporate capital input, price index (1958=1.000)	Private domestic capital input, quantity index (billions of 1958 dollars)	Private domestic capital input, price index (1958=1.000)	Index of relative utilization (1958=1.000)
1950	49.5	0.941	36.9	0.870	124.1	0.903	1.065
1951	53.2	1.034	37.9	.991	134.5	.965	1.092
1952	56.2	.977	38.5	.947	139.7	.969	1.046
1953	59.4	.968	39.8	.903	147.4	.932	1.048
1954	56.4	.958	39.3	.920	148.9	.966	1.029
1955	63.5	1.061	41.2	.896	158.6	.996	1.105
1956	66.6	1.024	42.1	.937	167.1	.971	1.106
1957	66.4	1.037	41.9	.938	171.9	.988	1.068
1958	67.8	1.000	41.2	1.000	178.1	1.000	1.000
1959	73.6	1.075	43.4	.987	183.5	1.028	1.082
1960	76.3	1.040	44.2	.950	189.0	1.024	1.058
1961	78.2	1.042	44.5	.903	194.1	1.043	1.035
1962	84.0	1.097	46.0	.980	202.3	1.081	1.137

Table 16.—Gross Private Domestic Capital Input, 1950–62 (Constant Prices of 1958)

Year	Private domestic capital stock (billions of 1958 dollars)	Potential capital input per unit of capital stock (percent)	Relative utilization of capital (1958=1.000)
1950	964.5	0.126	1.024
1951	1021.4	.127	1.035
1952	1068.5	.128	1.018
1953	1100.8	.129	1.037
1954	1134.6	.130	1.007
1955	1163.2	.131	1.040
1956	1213.0	.132	1.040
1957	1255.6	.133	1.036
1958	1287.9	.134	1.000
1959	1305.8	.135	1.038
1960	1341.4	.135	1.040
1961	1372.9	.136	1.035
1962	1398.1	.137	1.065

5. Measurement of Labor Input

5.1. Introduction

The labor input series used in this paper have also been borrowed from Christensen and Jorgenson. They are very similar to our original series except for the correction of an error in our original persons engaged series (it did not contain unpaid family workers) and the use of quality adjustments as extended by Griliches.[27] The Christensen-Jorgenson series add Kendrick's estimates of unpaid family workers to the OBE data on full-time equivalent employees and proprietors to arrive at a total persons engaged measure. Total man-hours in the private domestic sector are also based on Kendrick's series.[28]

Christensen and Jorgenson incorporate our original adjustment for the quality of the labor force based on the changing distribution of the labor force by years of school completed. They do not adjust, however, for the changing age-sex distribution of the labor force. An examination of the underlying labor force data indicates that there has been little relevant change in the age distribution of the employed in the 1950–62 period. There has been some relative increase in the number of young people in the labor force which has been largely counterbalanced by a decline in the proportion of older (above 65) employees. A pure age adjustment would have a very minor effect on our estimates.[29] There has been, however, an increase in the proportion of women in the labor force. We investigated the magnitude of an appropriate adjustment for this, using data on the average shares of men and women in total earnings during the years 1958–64, and the number of men and women employed in 1950 and 1958. The resulting adjustment is somewhat smaller but of the same order of magnitude as that reported by Denison for 1950–62.[30]

We also attempted to estimate a more detailed quality adjustment for men for the 1950–60 period, allowing for changes in education, age, race, and region (South and non-South). The basic data for this calculation were taken from Miller's monograph [65] and the associated Census volumes and refer to the population of men "with income", between the ages of 25 and 65. For this population, using the average of 1950 and 1960 income shares as weights, a straight education adjustment using average incomes by education for the population as a whole leads to an estimated 8.7 percent improvement in "quality." Using separate weights by region, race, age, and education leads to an estimated 12 percent rise in total labor quality, of which about 11 percent is due to the average improvement in the educational distribution within each age-race-region category and about 1 percent to the changing mix of these categories. In this case, a more detailed quality calculation for men produced a higher correction than the simple overall measure used by us. All this is just intended to indicate our belief that if we had developed a really detailed age-sex-race-region-education correction, it would as likely as not result in a higher rate of growth of labor input than was estimated by us originally.

5.2. Hours of work

Up to this point we have proceeded on the assumption that *hours per man* changed at the same rate for all categories of labor. If this is not the case, a more detailed labor input index is called for. The rate of growth in total labor should be measured by

$$\frac{\dot{L}}{L}=\sum v_i\frac{\dot{h}_i}{h_i}+\sum v_i\frac{\dot{n}_i}{n_i}$$

where n_i is the number of workers in the ith category, h_i are the hours per man worked by men in this category, and

$$v_i=w_ih_in_i/\sum w_ih_in_i=y_in_i/\sum y_in_i$$

is the share of the ith category of labor in total labor payments (w_i=wage per hour and $y_i=w_ih_i$=total earnings per man-year). Adding and subtracting $\dot{N}/N$ and $\dot{H}/H$, the rate of growth in total employment and the rate of growth in average hours worked per man, respectively, we can write

$$\frac{\dot{L}_t}{L_t}=\frac{\dot{N}}{N}+\frac{\dot{H}}{H}+\sum v_i\left(\frac{\dot{n}_i}{n_i}-\frac{\dot{N}}{N}\right)+\sum v_i\left(\frac{\dot{h}_i}{h_i}-\frac{\dot{H}}{H}\right)$$

$$=\frac{\dot{N}}{N}+\frac{\dot{H}}{H}+\sum v_i\frac{\dot{e}_i}{e_i}+\sum v_i\frac{\dot{m}_i}{m_i}$$

$$=\frac{\dot{N}}{N}+\frac{\dot{H}}{H}+\frac{\dot{E}}{E}+\frac{\dot{M}}{M}$$

where $e_i=n_i/N$ is the relative fraction of employment accounted for by the ith category and $m_i=h_i/H$ is its relative employment intensity (per year). $\dot{E}/E$ is then the rate of growth of average labor "quality" per man while $\dot{M}/M$ is the rate of growth in the relative quality of the average hour. In our original computations we left out the $\dot{M}/M$ term, assuming that all hours changed proportionately. To the extent that there has been a secular improvement in the employment experience of the educated versus uneducated, our index actually underestimates the "quality" improvement in the total labor force.

Unfortunately, the published data on hours and weeks worked per man from the 1950 and 1960 Censuses of Population [9, 10] were not cross-classified by education and hence we cannot construct a comparable $\dot{M}/M$ index. Some idea, however, of the direction and order of magnitude of such an adjustment can be gathered from scattered data on hours worked by occupation. These are summarized in table 17 and imply about a 0.2 percent rate of growth per annum in the quality of the average hour during the 1950–65 period. This, however, is somewhat of an overestimate, since during the 1950–60 period (the only one for which we have data) a similar measure of "quality" of weeks worked deteriorated at about −0.04 percent per year (see table 18). That is, while the decline of hours was relatively smaller for some of the "higher quality" categories, this was counterbalanced to some extent by the improved annual employment experience of several of the less well paid occupations. On net we would estimate $\dot{M}/M \cong 0.16$, which if multiplied by the average labor share would more than counterbalance (0.11 versus −0.09) the estimated decline in overall quality of the labor force due to the increased participation of females.

Many of these adjustments are small and well within the range of possible error in the data. We conclude, nevertheless, that our original estimate of the rate of growth of total labor input stands up rather well under reexamination and that a more thorough and detailed analysis would in all likelihood result in a higher rather than lower figure.

Table 17.—Average Hours Worked Per Week by Employed Persons at Work

Occupation	1950 [a]	1960 [a]	1960 [b]	1965 [b]	1959 weights [c]
Total	44.6	43.2	40.5	40.5	
Professional, technical, and kindred	44.1	46.9	41.3	41.4	.147
Farmers and farm managers	60.0	54.2	42.0	52.1	.031
Managers, etc., except farm	51.7	49.3	48.5	48.4	.192
Clerical and kindred	41.3	40.3	37.5	37.4	.063
Sales workers	45.1	43.9	38.2	37.3	.077
Craftsmen, etc.	41.6	42.1	41.0	42.3	.214
Operatives and kindred	42.0	42.2	40.3	41.2	.160
Private household workers	46.8	32.8	26.6	24.1	.002
Service workers except private household	44.7	41.9	38.7	37.8	.057
Farm laborers and foremen	48.5	48.2	39.3	39.4	.007
Laborers except farm and mine	39.9	37.1	35.0	35.5	.041

[a] Employed males. 1950 data computed from table 6, page 42, of Finegan [30]. The separate figures for self-employed and wage and salary workers were averaged using the numbers given in 1950 Census of Population [9], *Occupational Characteristics*, tables 14 and 15. The 1960 data are from 1960 U.S. *Census of Population* [10], *Occupational Characteristics*, table 13. Average hours for farm and service workers estimated for 1950 using Finegan's procedures. Both average hours figures are for the Census survey week.

[b] All persons at work, annual average, from Bureau of Labor Statistics, *Special Labor Force Reports* [16], 14 and 69.

[c] Computed from data on mean earnings of males 18 to 64 years of age and on the number of such males with earnings in 1959, from 1960 U.S. Census Population [10], *Occupation by Earnings and Education*. The service weight allocated between private household workers and other workers using median incomes from the *Occupational Characteristics* volume.

Rate of growth of quality of average hours per man:

		Per annum
$\Sigma w_i \frac{h_{it}}{h_{it-1}} - \frac{H_{Tt}}{H_{Tt-1}}$, 1950–60	2.30	0.23
1960–65	.79	.16

Table 18.—Average Weeks Worked by Males in the Experienced Civilian Labor Force [a]

Occupation	1949	1959
Total	46.1	46.6
Professional	48.9	47.8
Farmers and farm managers	47.4	47.7
Managers	48.6	48.6
Clerical	46.7	46.5
Sales workers	46.0	46.3
Craftsmen	45.4	46.2
Operatives	44.1	44.9
Private household workers	41.7	37.4
Service, except private household	44.7	37.4
Farm laborers	40.2	36.6
Laborers, except farm	41.0	39.7

[a] Average for those who worked in the particular year. Computed from the *Occupational Characteristics* volumes of the 1950 and 1960 Censuses of Population [9, 10]. Midpoints used: 50–52: 51; 40–49: 45; 27–39: 33; 14–26: 20; and 1–13: 7.

Rate of growth of quality of average week worked, using weights from table 17, can be computed as follows:

$$\left(\Sigma w_i \frac{W_{i\,1959}}{W_{i\,1949}}\right) - \frac{W_{T\,1959}}{W_{T\,1949}} = -0.36.$$

5.3. Price and quantity of labor services

The assumption that effective labor services are proportional to the stock of labor is obviously incorrect. On the other hand the assumption that effective labor services can be measured directly from data on man-hours is equally incorrect, as Denison [24] has pointed out. The intensity of effort varies with the number of hours worked per week, so that effective labor input can be measured accurately only if data on man-hours are corrected for the effects of variations in the number of hours per man on effective labor input. Denison [26] suggests that the stock of labor provides an upper bound for effective labor services while the number of man-hours provides a lower bound. He estimates effective labor input by correcting man-hours for variations in labor intensity. We employ Denison's correction for intensity, but we apply this correction to actual hours per man rather than potential hours per man, as in our original study.

Our current measure of labor services

Table 19.—Private Domestic Labor Input, 1950-62

Year	Private domestic persons engaged (millions)	Educational attainment per person (index) (1958=1.000)	Private domestic hours per person (thousands per year)	Effective labor input per hour (1958=1.000)	Private domestic labor input, quantity index (billions of 1958 dollars)	Private domestic labor input, price index (1958=1.000)
1950	52.973	0.948	2.197	0.978	228.8	0.683
1951	55.101	.954	2.186	.981	230.0	.742
1952	55.385	.960	2.187	.988	241.7	.782
1953	56.226	.965	2.169	.996	246.2	.827
1954	54.887	.971	2.139	.990	237.4	.846
1955	55.718	.977	2.161	.985	246.9	.880
1956	56.770	.982	2.151	.984	251.6	.930
1957	56.809	.988	2.121	.996	251.5	.978
1958	55.025	1.000	2.099	1.000	246.1	1.000
1959	56.216	1.012	2.122	.996	254.0	1.042
1960	56.742	1.020	2.126	.994	259.6	1.074
1961	56.211	1.028	2.110	.998	258.1	1.103
1962	57.076	1.036	2.117	.996	264.6	1.144

is based on the stock of labor as measured by persons engaged, adjusted for effective hours per person and for changes in the composition of the labor force by educational attainment. The cost of labor services index is calculated by dividing total labor compensation by the quantity index of labor services. The number of persons engaged, the index of quality change, actual hours per worker, effective labor input per man-hour, and the quantity of labor input for 1950–62 are given in table 19. The price of labor services implicit in private domestic labor compensation is also given in table 19. It would obviously be desirable to incorporate additional aspects of labor force composition in adjusting the stock of labor for quality change. It would also be desirable to adjust the number of hours per man for changes in the relative number of hours worked by persons differing in educational attainment. But as outlined above, this would require a data base that is much more detailed than anything currently available.

6. Measurement of Total Factor Productivity

6.1. Introduction

Total factor productivity is defined as the ratio of real product to real factor input, or equivalently, as the ratio of the price of factor input to the product price. Growth in total factor productivity has a counterpart in growth of the price of factor input relative to the price of output. We may define a Divisia index of total factor productivity, say P, as:

$$\log \frac{P_t}{P_{t-1}} = \log \frac{Y_t}{Y_{t-1}} - \log \frac{X_t}{X_{t-1}},$$

where Y is the quantity index of total product and X is the quantity index of total factor input.

To obtain an estimate of real factor input for the U.S. private domestic economy we combine estimates of labor and capital input. The basic data on labor input—number of persons engaged, educational attainment per person, and hours per person—are presented in table 19. The corresponding data on capital input—capital stock, potential service flow per unit of stock, and the relative utilization of capital—are presented in table 15. The index of educational attainment per person provides an adjustment of persons engaged for the aggregation bias that results from combining different types of labor into an unweighted aggregate. Similarly, capital stock is an unweighted aggregate; the index of potential capital services per unit of the capital stock provides an adjustment for aggregation bias. Potential capital services must be adjusted for relative utilization to obtain the actual flow of capital services. We construct price and quantity index numbers of factor input by combining Divisia indexes of labor and capital input into a Divisia index of total factor input. Price and quantity indexes for 1950–62 are given in table 20. The relative share of property compensation for the same period is also given in table 20.

To provide a detailed accounting for the sources of growth in real factor input, we can separate the growth of quantity indexes of labor and capital input into the growth of the stock, growth in the quantity of input due to shifts in composition of such unweighted aggregates as persons engaged and capital stock or "quality change",[31] and growth in relative utilization. The growth in labor input is the sum of

Table 20.—Gross Private Domestic Factor Input, 1950–62 (Constant Prices of 1958)

Year	Gross private domestic factor input, quantity index (billions of 1958 dollars)	Gross private domestic factor input, price index (1958=1.000)	Property compensation, relative share (percent)
1950	350.0	0.768	0.410
1951	371.3	.827	.423
1952	379.5	.850	.415
1953	391.5	.869	.404
1954	385.4	.880	.414
1955	404.3	.936	.422
1956	418.7	.947	.410
1957	423.4	.980	.407
1958	418.2	1.000	.414
1959	437.4	1.036	.414
1960	446.5	1.053	.410
1961	452.0	1.077	.415
1962	466.5	1.122	.422

growth in the number of persons engaged, the quality of the labor force, and the effective number of hours per person. The growth in capital input is the sum of growth in capital stock, the quality of capital, and relative utilization. Geometric average annual rates of growth for 1950–62 are given for each component of the growth of labor and capital input in table 21.

Table 21.—Sources of Growth in Factor Input, 1950–62

[Annual percentage rates of growth]

1. Capital input:	
a. Stock	3.14
b. Quality change	.70
c. Relative utilization	.25
2. Labor input:	
a. Stock	.63
b. Quality change	.75
c. Relative utilization	−.16

Price and quantity indexes of output are given above in table 3. The index of total factor productivity for 1950–62 corresponding to the quantity index of output from table 3 and the quantity index of gross private domestic factor input from table 20 is given in table 22. The conventions for measurement of factor services underlying our concept of gross private domestic factor input were employed in our original study. Our revised estimates, based on those of Christensen and Jorgenson, differ in two significant respects: First, we have converted the index of relative utilization to an annual basis and reduced the scope of adjustments of potential flows of capital services for changes in relative utilization. Second, we have measured the flow of capital services for sectors distinguished by legal form of organization in order to provide a more detailed representation of the tax structure. These differences have an important impact on the estimate of total factor productivity.

6.2. Alternative measures of productivity change

To provide a basis for comparison of our estimate of total factor productivity with estimates that result from alternative conventions for the measurement of real factor input, we present a number of variants based on alternative accounting conventions. We begin with an estimate of total factor productivity based on the actual flow of labor and capital services. We compare this estimate with alternatives based on potential flows of labor and capital services and on stocks of labor and capital. The services of consumers' durables and producers' durables used by institutions are allocated directly to final demand so that growth in the quantities of these services does not affect growth of total factor productivity. Similarly, the services of owner-occupied dwellings and institutional structures are allocated directly to final demand.

Kendrick and Solow use a stock concept of capital input, measuring neither changes in relative utilization nor changes in the quality of capital services due to changes in the composition of the capital stock.[32] Denison weights persons engaged by an index of labor quality that incorporates the effects of growth in educational attainment but differs in a number of important respects from the index we have used.[33] Denison also adjusts man-hours for changes in labor efficiency that accompany changes in hours per man.[34] Solow uses unweighted man-hours, omitting the effects of changes in the composition of the labor force on the quantity of labor input.[35] Kendrick adjusts labor and capital input for changes in the industrial composition of labor force and capital stock.[36] However, changes within an industial sector due to shifts in composition are not included in his measures of real factor input.

We present measures of total factor productivity based on potential service flows and on stocks of labor and capital in table 22. The first variant on our estimate of total factor productivity omits the relative utilization adjustment for capital, the second the relative utilization adjustment for labor; the second variant is based on potential service flows for both labor and capital input. The third variant omits the quality adjustment for capital, while the fourth omits the quality adjustment for labor, providing a stock measure of total factor productivity. Two final variants provide combinations of alternative measures of labor input with the stock measure of capital. The fifth combines actual labor input with the stock of capital, while the sixth combines unweighted actual man-hours with capital stock, It is obvious from a comparison of the alternative estimates of total factor productivity given in table 22 that the results are highly sensitive to the choice of conventions for measuring real factor input The effects of varying the convention

Table 22.—Total Factor Productivity, 1950–62 (1958=1.000)

Year	Labor and capital services	Actual labor services; potential capital services	Potential labor and capital services	Potential labor services; capital stock	Labor and capital stock	Actual labor services; capital stock	Unweighted man-hours; capital stock
1950	0.939	0.948	0.961	0.935	0.906	0.922	0.892
1951	.946	.960	.971	.949	.923	.938	.902
1952	.949	.956	.967	.949	.927	.938	.904
1953	.968	.993	.990	.974	.954	.966	.939
1954	.974	.977	.982	.966	.948	.964	.942
1955	1.006	1.023	1.031	1.020	1.006	1.012	.989
1956	.994	1.010	1.018	1.011	1.001	1.004	.998
1957	.996	1.009	1.012	1.008	1.002	1.008	.996
1958	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1959	1.019	1.034	1.038	1.030	1.046	1.035	1.029
1960	1.019	1.056	1.040	1.043	1.056	1.039	1.048
1961	1.031	1.046	1.048	1.064	1.072	1.058	1.068
1962	1.062	1.094	1.068	1.097	1.120	1.094	1.114

are summarized for the period 1950–62 in table 23; geometric average annual rates of growth are given for each variant of total factor productivity.

Table 23.—Growth in Total Factor Productivity, 1950–62

[Average annual rates of growth]

1. Actual labor and capital services	1.03
2. Actual labor services; potential capital services	1.14
3. Potential labor and capital services	1.04
4. Potential labor services; capital stock	1.34
5. Labor and capital stock	1.78
6. Actual labor services; capital stock	1.44
7. Man-hours and capital stock	1.96

6.3. Sources of U.S. economic growth, 1950–62

Finally, to evaluate the relative importance of growth in real factor input and growth in total factor productivity as sources of economic growth, we consider the relative proportion of growth in real factor input. Geometric average annual rates of growth are given for real product and real factor input for 1950–62 in table 24. The relative proportion of growth in total factor productivity in the growth of real product is also provided.

We find that the growth in real factor input predominates in the explanation of the growth of real product for the period 1950–62. These findings are directly contrary to those of Abramovitz [1], Kendrick [61, 62] and Solow [70] in earlier studies of productivity change. We have estimated real factor input on the basis of capital stock and actual man-hours, the conventions used by Solow and subsequently adopted by Arrow, Chenery, Minhas, and Solow [3], 1950–62. The resulting estimates of the distribution of the growth of real product between growth in real factor input and total factor productivity are comparable to those of Solow's earlier study. On the basis of our data and Solow's conventions total factor productivity grows at the average rate of 1.96 percent per year while real factor input grows at 1.51 percent per year. Our estimates, given in table 24, are that total factor productivity grows at 1.03 percent per year and real factor input at the rate of 2.42 percent per year.

Table 24.—The Relative Importance of Productivity Change, 1950–62

[Average annual rates of growth]

Gross private domestic product:		
Real product		3.47
Real factor input		2.42
Capital input:		
Stock	1.30	
Quality change	.30	
Relative utilization	.11	
Labor input:		
Stock	.37	
Quality change	.44	
Relative utilization	−.10	
Total factor productivity		1.03
Relative proportion of productivity change		.30

We also present estimates of real factor input based on capital stock and actual labor input, which provide the best approximation to the conventions adopted by Denison [28]. Denison finds that total factor productivity grows at 1.37 percent per year, not adjusted for intensity of demand. We find that estimates of real factor input based on our data suggest that total factor productivity grows at the average rate of 1.44 percent per year while real factor input grows at 2.03 percent per year. The discrepancy between estimates based on our conventions, given in table 23, and those based on capital stock and actual labor input is accounted for almost entirely by our adjustments of the measure of capital input for quality change and relative utilization. Denison has incorporated about half the growth in real factor input over and above the growth of capital stock and actual man-hours into his estimates of real factor input.

7. Major Issues in Growth Accounting

7.1. Introduction

Denison has examined our approach to productivity measurement in his paper, "Some Major Issues in Productivity Analysis: An Examination of Estimates by Jorgenson and Griliches" [25]. Denison's detailed examination of our estimates contributes significantly to the definition of unresolved issues in the measurement of total factor productivity. This contribution is especially valuable in view of the underlying agreement between our objectives and Denison's objectives in his pathbreaking studies of productivity change [26, 28]. Although the basic agreement between our objectives in productivity measurement and Denison's is reassuring, important differences in methods of measurement and in substantive conclusions remain.

We have attempted to indicate the quantitative magnitude of disagreement between Denison's estimates of total factor productivity and ours by reworking our estimates in order to provide a direct comparison among the results of three different approaches to the measurement of total factor productivity—the conventional approach, Denison's approach, and our own approach. We have concentrated on the period 1950–62 employed by Denison in his most recent study, *Why Growth Rates Differ* [28]. For convenience of the reader we follow the order of topics in Denison's paper [25].

7.2. Scope of product

We begin our examination of the issues raised by Denison with an analysis of the effects of the concept of real product on the measurement of productivity change. Denison regards both gross and net product measures as legitimate for productivity analysis,[37] but gives priority to the net product measure: "Insofar as a larger output is a proper goal of society and objective of policy, it is net product that measures the degree of success in achieving this goal. Gross product is larger by the value of capital consumption. There is no more reason to wish to maximize capital consumption—the quantity of capital goods used up in production—than there is to maximize the quantity of any other intermediate product . . ."[38]

The first problem with Denison's argument is that the difference between gross product and net product is equal to depreciation, while the quantity of capital goods used up in production is equal to replacement. Depreciation is equal to replacement if and only if the decline in efficiency of capital goods is geometric. Under Denison's characterization of decline in efficiency, depreciation is not equal to replacement, so that Denison's argument is internally contradictory.[39] This contradiction can be removed by defining net product as gross product less depreciation.

In the estimates of productivity change given in Section 6 above, the decline in efficiency of capital goods is assumed to be geometric so that depreciation and replacement are equal. Our product measure is gross product from the producers' point of view. Under our assumptions, Denison's argument justifying net product as a product measure is irrelevant to productivity measurement. Net product is associated with precisely the same measure of the absolute contribution of productivity change as gross product from the producers' point of view. Denison's argument provides no basis for discriminating between net and gross product as a basis for productivity measurement. Furthermore, the measure of the absolute contribution of productivity change is the same for our measure of gross product and for gross product at factor cost, the gross product concept Denison prefers for productivity analysis.[40]

The contribution of productivity change may be expressed as the absolute amount of growth in real product accounted for by changes in productivity.[41] This contribution is equal to the difference between period to period changes in real product and changes in real factor input. The contribution of productivity change may be expressed relative to any of the alternative concepts of real product, gross product from the producers' point of view, gross product at factor cost, and net product. Alternative measures of relative productivity change differ only in the concept of real product employed, not in the measure of the absolute contribution of productivity change.

We first demonstrate that the absolute contribution of productivity change is the same for gross product from the producers' point of view, gross product at factor cost, and net product. The difference between gross product from the producers' point of view and gross product at factor cost is indirect taxes on factors of production, such as property taxes. These taxes appear as part of both output and input and leave the absolute contribution of productivity change unaffected. The difference between gross product and net product is depreciation. Depreciation also appears as part of both output and input, leaving the contribution of productivity change unaffected. Problems that arise in measuring the depreciation component of gross capital input also arise in measuring depreciation to convert gross product to net product. The data required for measurement of gross product from the producers' point of view, gross product at factor cost, and net product are identical.

The absolute contribution of productivity change to the growth of real output is the difference between changes in output and changes in input, both evaluated at current prices; this is equal to the difference between changes in the prices of output and input, each multiplied by the corresponding quantity:

$$q\dot{Y}-p\dot{X}=\dot{p}X-\dot{q}Y.$$

The relative contribution of productivity change, say $\dot{P}/P$, is obtained by dividing the absolute contribution by the value of output (or input):

$$\frac{\dot{P}}{P}=\frac{q\dot{Y}-p\dot{X}}{qY}=\frac{q\dot{Y}}{qY}-\frac{p\dot{X}}{pX}=\frac{\dot{Y}}{Y}-\frac{\dot{X}}{X}.$$

Dividing output between consumption and investment goods and input between capital and labor services, the identity between the value of output and the value of input may be written:

$$q_CC+q_II=p_KK+p_LL,$$

where C and I are quantities of consumption and investment goods and K and L are quantities of capital and labor input. The corresponding prices are denoted q_C, q_I, p_K, and p_L. To represent gross value added from the producers' point of view we suppose for simplicity that tax depreciation and economic depreciation are the same. Under this simplifying assumption the price of capital services may be written:[42]

$$p_K=q_I\left(\rho+\mu+\tau-\frac{\dot{q}_I}{q_I}\right),$$

where ρ is the (before-tax) rate of return, μ the rate of depreciation, and τ the rate of indirect taxation of property. The accounting identity may then be rewritten:

$$q_CC+q_II=q_I\left(\rho+\mu+\tau-\frac{\dot{q}_I}{q_I}\right)K+p_LL.$$

Identifying the change in the aggregate quantity of output with the sum of changes in consumption and investment goods output, evaluated at current prices, and defining the change in aggregate input similarly, the absolute contribution of productivity change may be represented in the form:

$$q_C\dot{C}+q_I\dot{I}-q_I\left(\rho+\mu+\tau-\frac{\dot{q}_I}{q_I}\right)\dot{K}-p_L\dot{L}.$$

To obtain corresponding measures of the contribution of productivity change for alternative concepts of social product, we first derive gross product at factor cost by subtracting the value of property taxes from both sides of the basic accounting identity, obtaining:

$$q_CC+q_I(I-\tau K)=q_I\left(\rho+\mu-\frac{\dot{q}_I}{q_I}\right)K+p_LL.$$

Defining the absolute contribution of productivity change as before we obtain:

$$q_C\dot{C}+q_I(\dot{I}-\tau\dot{K})-q_I\left(\rho+\mu-\frac{\dot{q}_I}{q_I}\right)\dot{K}-p_L\dot{L}$$

$$=q_C\dot{C}+q_I\dot{I}-q_I\left(\rho+\mu+\tau-\frac{\dot{q}_I}{q_I}\right)\dot{K}-p_L\dot{L}$$

which is identical to the contribution of productivity change for gross product from the producers' point of view.

Second, we derive net product by subtracting the value of depreciation from both sides of the identity given above:

$$q_C C + q_I[I-(r+\mu)K] = q_I\left(\rho - \frac{\dot{q}_I}{q_I}\right)K + p_L L.$$

The resulting measure of the absolute contribution of productivity change is the same as for gross value added:

$$q_C \dot{C} + q_I[\dot{I}-(r+\mu)\dot{K}] - q_I\left(\rho - \frac{\dot{q}_I}{q_I}\right)\dot{K} - p_L \dot{L}$$

$$= q_C \dot{C} + q_I \dot{I} - q_I\left(\rho + \mu + r - \frac{\dot{q}_I}{q_I}\right)\dot{K} - p_L \dot{L}.$$

We conclude that the measure of productivity change in absolute terms is the same for all three concepts of real product we have considered—gross product from the producers' point of view, gross product at factor cost, and net product. The absolute contribution of productivity change may be expressed relative to any measure of output. Alternative measures of relative productivity change differ in the concept of output employed as a standard of comparison, but not in the measure of the absolute contribution of productivity change.

The absolute contribution of productivity change has the important property that the contribution to the growth of the economy as a whole is the sum of contributions to the growth of individual sectors. This property is maintained for measures of output of an economic sector that include intermediate goods purchased from other sectors, as in interindustry studies. Intermediate goods appear as real output in the sector of origin and real input in the sector of destination. Changes in the output of intermediate goods cancel out in any measure of the contribution of productivity change to the economy as a whole.

In our original estimates we used gross product at market prices; we now employ gross product from the producers' point of view, which includes indirect taxes levied on factor outlay, but excludes indirect taxes levied on output. Denison employs net product, which excludes all indirect taxes and depreciation along with a number of minor items. Our revised product measure covers the private domestic economy, incorporating the services of durables used by households and institutions along with the services of structures used in this sector. Our original product measure did not include the services of durables used by households and institutions. Denison covers the entire national economy. Our revised product measure provides for a more satisfactory treatment of indirect taxes. It also treats durables symmetrically with structures in the household sector.

To reconcile our revised product measure with Denison's it would be necessary to exclude the services of durables used by households and institutions and to eliminate indirect taxes and depreciation at replacement cost. The product of government and rest of the world sectors would have to be added. None of these changes would alter our estimate of the absolute contribution of productivity change. Any difference in percentage rates of growth of total factor productivity would be due to the product measure relative to which productivity change is expressed. The more comprehensive the product measure the less the relative rate of growth of total factor productivity associated with any absolute contribution of productivity change. To adjust estimates of the relative growth of total factor productivity based on our data to a net national product basis, percentage rates of growth should be multiplied by the ratio of gross product to net national product in each period. A similar adjustment can be made to convert relative rates of growth of total factor productivity to any other product measure.

7.3. Index numbers

To separate flows of product and factor outlay into prices and quantities, we introduce price and quantity index numbers. As an example, suppose that there are m components to the value of output,

$$qY = q_1 Y_1 + q_2 Y_2 + \ldots + q_m Y_m.$$

Index numbers for the price of output q and the quantity of output Y may be defined in terms of the prices $[q_i]$ and quantities $[Y_i]$ of the m components. Differentiating the value of output totally with respect to time and dividing both sides by total value,

$$\frac{\dot{q}}{q} + \frac{\dot{Y}}{Y} = \sum w_i\left[\frac{\dot{q}_i}{q_i} + \frac{\dot{Y}_i}{Y_i}\right];$$

weights $[w_i]$ are the relative shares of the value of the ith output:

$$w_i = \frac{q_i Y_i}{\sum q_i Y_i}.$$

We define the price and quantity indexes of output as weighted averages of rates of growth of prices and quantities of individual components:

$$\frac{\dot{q}}{q} = \sum w_i \frac{\dot{q}_i}{q_i}, \quad \frac{\dot{Y}}{Y} = \sum w_i \frac{\dot{Y}_i}{Y_i},$$

obtaining Divisia price and quantity indexes.[43] Rates of growth of the Divisia indexes of prices and quantities add up to the rate of growth of the value (factor reversal test) and are symmetric in different directions of time (time reversal test). A Divisia index of Divisia indexes is a Divisia index of the components.

For application to data for discrete points of time an approximation to the continuous Divisia indexes is required. Price and quantity index numbers originally discussed by Fisher [31] have been employed for this purpose by Tornquist [74]:

$$\log q_t - \log q_{t-1} = \sum \bar{w}_{it}\,[\log q_{it} - \log q_{i,t-1}],$$

$$\log Y_t - \log Y_{t-1} = \sum \bar{w}_{it}\,[\log Y_{it} - \log Y_{i,t-1}],$$

where the weights $\bar{w}_{it}$ are arithmetic averages of the relative shares in the two periods,

$$\bar{w}_{it} = \frac{1}{2} w_{it} + \frac{1}{2} w_{i,t-1}.$$

A discrete Divisia index of discrete Divisia indexes is a discrete Divisia index of the components. Divisia index numbers for discrete time are also symmetric in data of different time periods (time reversal). Theil [72] has demonstrated that the sum of changes in logarithms of discrete Divisia indexes of price and quantity is approximately equal to the change in the logarithm of the value (factor reversal). It is convenient to have the product of price and quantity indexes equal to the value of transactions, so that we construct discrete Divisia price indexes as the value in current prices divided by the discrete Divisia quantity index.

The estimates of Christensen and Jorgenson [19, 20] are based on a different discrete approximation to Divisia index numbers from that employed in our original estimates; the results are essentially unaffected for the period 1950–62. Denison's estimates are based on an alternative discrete approximation. The three approximations appear to produce essentially similar results. Our approximation satisfies both time reversal and, approximately, factor reversal tests for index numbers.

7.4. *Capital and labor weights*

The value of labor input includes labor compensation of employees and the self-employed. Our estimates of the labor compensation of the self-employed are based on the assumption that average labor compensation of the self-employed in each sector is equal to average labor compensation of full-time equivalent employees in each sector. This method of imputation of the labor compensation of the self-employed is only one of many that have been proposed. Our original method did not separate labor and property components of noncorporate income by industrial sector. Our new method, discussed in detail by Christensen [18], has the effect of allocating a larger share of factor outlay to capital, overcoming Denison's objection to our original method.[44] The resulting rates of return in corporate and noncorporate sectors are essentially the same, taking into account the effect of the corporate income tax. The revised allocation of noncorporate income seems to us to be superior to our original allocation and to Denison's allocation.[45]

Second, the concept of gross product from the producers' point of view enables us to eliminate an error in our original allocation of indirect tax liability.[46] Our original concept of gross product at market prices included sales and excise taxes and customs duties in the earnings of capital. Our present estimates include only taxes levied on income from property. This measure of capital earnings is the appropriate one, given our concept of gross product from the producers' point of view. The implied weights for labor and capital meet Denison's objections to our original treatment of indirect business taxes.[47]

7.5. *Weights for components of capital and land*

The major difference between our measure of total factor input and Denison's is in the assignment of relative weights to components of land and capital input. An ideal measure of capital input is strictly analogous to an ideal measure of labor input. Both measures combine rates of growth of individual components into an overall rate of growth, using relative shares of the individual components as weights. While factor shares for components of labor can be estimated from data on wages and employment, factor shares for components of capital must be imputed from accounting data on total property income. The problem for productivity measurement is to provide a practical method for carrying out this accounting imputation. Our method of imputation is described in detail in Section 3 above.

Our original estimates, like those of Denison, distinguished alternative capital inputs by class of asset. For the private domestic economy we distinguished among five categories of assets—land, residential structures, nonresidential structures, equipment, and inventories. For this sector of the economy Denison distinguishes between residential and nonresidential land; otherwise the breakdown of assets is the same. Neither of these breakdowns is fully satisfactory for the incorporation of the effects of the tax structure on property income.

In our revised estimates inventories are allocated between farm and nonfarm sectors and consumers' durables are introduced as a new and separate class of assets. Each of the seven classes of assets is then allocated among sectors that differ in legal form of organization—corporate, noncorporate, and households and institutions. We assume, following Christensen and Jorgenson [19], that the rates of return on all assets held within a given sector are the same. Property income in the corporate sector is subject to both corporate and personal income taxes. Noncorporate property income is subject only to the personal income tax. The property income of households and institutions is subject to neither tax. This new, more detailed, asset classification enables us to meet a number of valid objections Denison has raised to our original treatment of the tax structure.[48]

Our new estimates incorporate the tax structure for property income in a more satisfactory way than our original estimates. Property taxes are separated from other earnings from capital and treated as tax deductible for income tax purposes. Depreciation for tax purposes is incorporated at its present value for the lifetime of an asset, so that the effects of accelerated depreciation are simultaneous with the adoption of the depreciation provisions of the Internal Revenue Act of 1954. Our revised estimates also incorporate the investment tax credit adopted in 1962. The rate of the investment tax credit and the rate of the corporate income tax are effective rates, measured from national accounting data.

Denison incorporates part of the tax structure implicitly by excluding property taxes from his measure of social product. This procedure is equivalent to our treatment of property taxes for the purposes of measuring absolute productivity change. Denison's estimates do not take explicit account of direct taxation of income from property. He distinguishes among property income in housing, agricultural, and all other sectors of the economy, but this breakdown of the economy does not coincide with the breakdown associated with the structure of taxation of property income. The availability of data on property income by legal form of organization from the U.S. national accounts makes it possible to improve on Denison's treatment of property income and on our original estimates. We conclude that Denison's classification of assets, like our original classification, fails to capture differences in direct taxation of property income for enterprises that differ in legal form of organization. Denison's estimates of property income fail to incorporate depreciation for tax purposes and the investment tax credit in a satisfactory way.

The rates of return included in our capital service prices are real rates of return rather than nominal rates of return. Nominal rates are assumed to be the same for all assets within a given sector. Real rates differ by differentials between rates of growth of asset prices for different classes of assets. The allocation of property income among asset classes depends on differentials among rates of growth of prices. If all asset prices are growing at the same rate, real rates of return are the same for all assets within each sector. Denison objects to the use of real rates of return on the grounds that price changes in assets other than land are always unanticipated.[49] His proposed procedure would amount to ignoring differentials among assets other than land and to setting the differential between land and other assets equal to the rate of growth of land prices. For the 1950–62 period land prices grow more rapidly than other asset prices, but there is substantial inflation in the price of structures and producers' durables. On the other hand the price of farm inventories actually falls. It is clear that Denison's proposed procedure, or his actual practice of ignoring differential rates of inflation,[50] introduces distortions in the allocation of property income among asset classes.

A serious accounting problem arises in attempting to integrate Denison's proposed allocation of property income among assets into national accounts for saving and wealth. Changes in the value of national wealth are equal to saving plus capital gains from the revaluation of assets. Saving is equal to labor income less consumption plus property income less depreciation. These definitions hold for individual wealth holders as well as for the economy as a whole. Capital gains from the revaluation of assets must be taken into account in allocating property income among capital assets and, implicitly, among individual wealth holders. The changes in the value of assets that enter individual and national wealth accounts must be consistent with the property income attributed to those assets in individual and national income accounts. The use of real rates of return is necessitated by internal consistency of the complete system of national accounts. Capital gains should be incorporated into the allocation of property income among classes of assets. Denison is in error, not only in failing to take capital gains into account in measuring income from land, but in omitting capital gains in measuring income from other assets.[51] We conclude that Denison's proposed allocation of property income among assets is inconsistent with the integration of property income into individual and national accounts for saving and wealth.

Finally, Denison defends Kendrick's exclusion of depreciation on the grounds that Kendrick uses net product and net earnings from capital in measuring total factor productivity.[52] Actually, Kendrick employs both net and gross measures of output and uses net earnings for allocating property income for both, which is the error we originally pointed out.[53] Denison is in error in asserting that we recommend the inclusion of depreciation in weights for the analysis of net product and in associating himself with Kendrick's weighting scheme.[54]

The most serious problem with Denison's treatment of depreciation is the lack of consistency between depreciation as it enters his measure of real product and the corresponding treatment of capital assets in his measure of real factor input. In Section 3.2 above we have outlined a perpetual inventory method for measurement of depreciation and capital assets based on the assumption that the service flow from an investment good declines geometrically. To describe Denison's method, we must generalize our treatment to alternative assumptions about the time pattern of the service flow. We assume that the relative efficiency of the ith investment good may be described by a sequence of nonnegative numbers,

$$d_{i0}, d_{i1} \ldots .$$

Denison points out, correctly, that a capital input measure depends on the relative efficiency of capital goods of different ages:

> In principle, the selection of a capital input measure should depend on the changes that occur in the ability of a capital good to contribute to net production as the good grows older (within the span of its economic life). Use of net stock, with depreciation computed by the straight line formula, would imply that this ability drops very rapidly—that it is reduced by one-fourth when one-fourth of the service life has passed, and by nine-tenths when nine-tenths of the service life has passed. Use of gross stock would imply that this ability is constant throughout the service life of a capital good.[55]

Denison argues, further, that:

> I believe that net value typically declines more rapidly than does the ability of a capital good to contribute to production. . . . On the other hand, the gross stock assumption of constant services throughout the life of an asset is extreme.[56]

Under our assumption, that decline in efficiency is geometric:

$$d_{i\tau}=(1-\mu_i)^{\tau},\ (\tau=0,1,\ \ldots\ ).$$

Under Denison's gross stock assumption relative efficiency is constant over the economic lifetime of the equipment:

$$d_{i\tau}=1,\ (\tau=0,1,\ \ldots\ ,\ T_i-1),$$

where T_i is economic lifetime of the ith investment good. Under Denison's net stock assumption, efficiency declines linearly

$$d_{i\tau}=1-\frac{1}{T_i}\tau \qquad (\tau=0,1,\ \ldots\ ,\ T_i-1),$$

where $\frac{1}{T_i}$ is the rate of decrease in efficiency of the ith investment good from period to period.

Capital stock at the end of the period, say K_{it}, is the sum of past investments, say $\{I_{i,t-\tau}\}$ each weighted by its relative efficiency:

$$K_{it}=\sum_{\tau=0}^{\infty} d_{i\tau} I_{i,t-\tau}.$$

With a geometric decline in efficiency we obtain the capital stock measures used in Section 3 above. With constant relative efficiency we obtain Denison's gross stock measure; with linear decline in relative efficiency, we obtain Denison's net stock measure. In Denison's study, *Sources of Economic Growth* [26], gross stock is employed as a measure of capital input. In *Why Growth Rates Differ* [28, p. 141] an arithmetic average of gross stock and net stock is employed; the implied relative efficiency of capital goods is an average of constant and linearly declining relative efficiency,

$$d_{i\tau}=1-\frac{1}{2T_i}\tau \qquad (\tau=0,1,\ldots,T_i-1)$$

where $\frac{1}{2T_i}$ is the rate of decrease in efficiency.

Replacement requirements, say R_{it}, are a weighted average of past investments with weights given by the mortality distribution:

$$R_{it}=\sum_{\tau=1}^{\infty} m_{i\tau} I_{i,t-\tau}$$

where:

$$m_{i\tau}=-(d_{i\tau}-d_{i,\tau-1}),\ (\tau=1,2,\ldots).$$

For geometric decline in efficiency, replacement requirements are proportional to capital stock,

$$R_{it}=\mu_i K_{i,t-1}.$$

Turning to asset and service prices, the price of the ith asset is equal to the discounted value of future services:

$$q_{it}^A=\sum_{\tau=t}^{\infty}\prod_{s=t+1}^{\tau+1}\frac{1}{1+r_s}p^K_{i,\tau+1}d_{i,\tau-t}.$$

Depreciation on a capital good is a weighted average of future rental price with weights given by the mortality distribution:

$$q_{it}^D=\sum_{\tau=t}^{\infty}\prod_{s=t+1}^{\tau+1}\frac{1}{1+r_s}p_{i,\tau+1}^K m_{i,\tau-t}.$$

For geometric decline in efficiency depreciation is proportional to the asset price:

$$q_{it}^D=\mu_i q_{it}^A.$$

Depreciation and replacement must be carefully distinguished in order to preserve consistency between the treatment of capital services and the treatment of capital assets. Depreciation is a component of the price of capital services. The value of capital services is equal to property income, including depreciation. Replacement is the consequence of a reduction in the efficiency of capital assets or, in Denison's language, the ability of a capital good to contribute to production. The value of depreciation is equal to the value of replacement if and only if decline in efficiency is geometric:

$$q_{it}^D K_{i,t-1}=\mu_i q_{it}^A K_{i,t-1}=q_{it}^A R_{it}.$$

Otherwise, replacement and depreciation are not equal to each other. Replacement reflects the current decline in efficiency of all capital goods acquired in the past. Depreciation reflects the current value (present discounted value) of all future declines in efficiency on all capital goods.

A confusion between depreciation and replacement pervades Denison's treatment of real product, real factor input, and capital stock. The first indication of this confusion is Denison's definition of net product: "Net product measures the amount a nation consumes plus the addition it makes to its capital stock. Stated another way, it is the amount of its output a nation could consume without changing its stock of capital." [57] The correct definition of net product is gross product less depreciation; this is the definition suggested by Denison's second statement quoted above. The first statement defines net product as gross product less replacement, since the addition to capital stock is equal to investment less replacement. The two definitions are consistent if and only if depreciation is equal to replacement, that is, if and only if decline in efficiency is geometric.

Denison measures capital consumption allowances on the basis of Bulletin F lives and the straight line method.[58] Under the assumption that relative efficiency (Denison's "ability to contribute" to production) declines linearly, this estimate corresponds to replacement rather than depreciation. To measure net product Denison reduces gross product by his estimate of capital consumption allowances.[59] Since his estimate of capital consumption allowances is a measure of replacement, this procedure employs the incorrect definition of net product as consumption plus investment less replacement. This inappropriate measure of net product is reduced by labor compensation to obtain property income net of capital consumption allowances. Thus, Denison's measure of property income is also net of replacement rather than depreciation. This erroneous measure is allocated among capital inputs to obtain weights employed in measuring capital input as a component of real factor input; Denison's weights for different components of capital input are measured incorrectly. These weights should reflect property income less depreciation; in fact, they reflect property income less replacement.

The final confusion in Denison's treatment of capital in *Why Growth Rates Differ* [28] arises in the adoption of an arithmetic average of gross and net stock as a measure of capital input. As indicated above, this measure of capital input implies that efficiency declines linearly up to the end of an asset's economic lifetime; at that point half the asset's "ability to contribute" to production remains so that all the remaining decline in efficiency takes place in one year. Denison's measure of capital consumption allowances by the straight-line method fails to measure either replacement or depreciation. We conclude that Denison's treatment of capital consumption allowances in the measurement of net product and net factor input is inconsistent with his treatment of capital assets in the measure of real capital input that is incorporated into his measure of real factor input. A similar problem arises in Denison's earlier study, *Sources of Economic Growth* [26]. There gross product is employed as a measure of capital input.[60] Denison's measure of capital consumption allowances corresponds to replacement rather than depreciation so that his measures of net product and net factor input are inconsistent with his measure of capital input.

We assume that the decline in efficiency of capital goods is geometric; under this assumption depreciation and replacement are equal, so that the inconsistencies in Denison's procedure outlined above do not arise. If we were to assume that the decline in efficiency is linear, as in Denison's arithmetic average of net and gross stock, depreciation would be measured differently from replacement. The first step would be to estimate the value of capital assets of each age at each point of time as the discounted value of future capital services. This is the definition of net stock suggested by Denison,[61] but not the definition used in his measure of net stock, which is net of replacement rather than net of depreciation.[62] The second step would be to estimate depreciation on capital goods of each age by discounting the mortality distribution, as indicated above in the definition of depreciation q_{t}^{D}. The third step would be to obtain total depreciation as the sum over all types of capital goods and all ages. Only at this point would it be possible to measure net product as gross product less depreciation.

It is clear that the selection of an appropriate assumption about the decline in efficiency of capital goods is both important and difficult. We selected geometrically declining efficiency on the basis of its convenience and consistency with scattered empirical evidence. The available evidence arises from two sources—studies of replacement investment and studies of depreciation in the market prices of capital goods. Geometric decline in efficiency has been employed by Hickman and by Hall and Jorgenson in studies of investment.[63] This assumption has been tested by Meyer and Kuh, who find no effect of the age distribution of capital stock in the determination of replacement investment.[64] Geometric decline in efficiency has been employed in the study of depreciation on capital goods by Cagan, Griliches, and Wykoff.[65] This assumption has been tested by Hall, who finds no effect of the age of a capital good in the determination of depreciation as measured from the prices of used capital goods.[66] The power of these tests is not high and some contrary evidence is presented by Griliches.[67] Nevertheless, the weight of the evidence suggests that Denison's treatment of capital could be radically simplified and made internally consistent by adopting our assumption of geometric decline in efficiency of capital goods. Any alternative assumption about the decline in efficiency requires redefinition of Denison's measures of replacement, depreciation, and capital stock to make them consistent.

A conceptual issue that can be clarified at this point is the role of disaggregation in the measurement of real product and real factor input. Our original presentation included an extensive discussion of two alternative concepts of "quality change" in productivity analysis.[68] We indicated that quality change in the sense of "aggregation error" should be eliminated by disaggregating product and factor input measures so as to treat distinct products and factors as separate commodities wherever possible. The term quality change is often used in a different sense. Estimates of quality change are sometimes made by attributing changes in productivity to changes in the quality of a particular factor *without disaggregation*.

A particularly graphic example of inappropriate use of quality change occurs in the analysis of the "vintage" model of capital. The correct measure of quality change across vintages would require data on the price and quantity of capital services for each vintage at each point of time. Aggregation over vintages could then be carried out in the same way as any other type of aggregation and biases due to quality change could be eliminated.[69] In the absence of the required data, productivity change itself has been employed to estimate the quantity of capital input corrected for quality change.[70] Denison registers disagreement with this approach to the problem of quality change;[71] in fact, our view of this problem is identical to Denison's.

If it were possible to implement our original suggestion that different vintages of capital goods be weighted in measuring capital input by their marginal products, this would not have the effect of incorporating "embodied" technical progress, as Denison [25, p. 26] suggests. In fact the position attributed to us by Denison, the use of "unmeasured" quality change to correct capital input for changes in quality by vintage, is precisely the position we originally rejected [60, p. 260]. Of course implementation of our suggestion would require data on service prices by vintage at each point of time.

7.6. Measurement of capital and land

Our estimates of the value of land are revised considerably from the Goldsmith estimates employed in our original paper.[72] While we have assumed that nonresidential land has remained constant, this assumption could be improved upon. There are scattered data on types of land, their relative value, and the changing composition of land actually in use in the private economy. Very little of the investment related to shifts of land from one category of use to another is captured in the standard investment series. Some of these investments are directly expensed and others are government subsidized. A rough measure of the effects of shifts in the use of land to higher valued urban uses from 1945 to 1958 can be constructed from Goldsmith's data. Land input rises 1.4 percent per year by this measure.[73] If this figure were extrapolated to the 1950–62 period it would raise our estimated growth of total factor input by 0.14 percent per year.

Our estimates of the stocks of inventories and depreciable assets are based on those of OBE. Estimates of depreciable assets for corporate and noncorporate sectors are based on the OBE Capital Goods Study [49]. Our perpetual inventory estimates of stocks of residential structures and durables used by households are based on methods similar to those employed in the Capital Goods Study. The main difference between our estimates of capital stock and Denison's is in our use of declining balance depreciation. Denison uses a mixture of the one-hoss-shay and the straight-line method,[74] which gives rise to the problems in maintianing internal consistency among depreciation, replacement, and capital stock outlined above.

Our original estimates of capital input were based on price indexes that attempted to correct for various biases in the deflators employed in the U.S. national accounts. Since a positive bias in the investment goods price index results in underestimation of the growth of both product and capital input, correction of biases does not affect estimates of total factor productivity substantially. Our present estimates, based on those of Christensen and Jorgenson [19, 20] are conservative in the choice of price deflators. We use national accounts deflators except for structures; for both residential and nonresidential structures we employ OBE "constant cost 2" as a price deflator.[75] We also incorporate both asset and investment deflators for inventories, overcoming another of Denison's objections to our original estimates.[76] Finally, we did not replace the producers' durable equipment price index by the comparable consumers' durable series, a practice Denison objects to but which we have defended above.[77] Thus, there is no practical difference between the price series we use and those recommended by Denison.

7.7. Utilization adjustment

Denison directs his strongest criticisms, and correctly so, against what is probably the weakest link in our chain. While we have accepted most of his criticism, we still believe that the question posed by our utilization adjustment is interesting, the numbers used are not all that bad, and something has been learned from this exercise.

Denison's criticisms can be summarized under the following headings:

(1) the basic numbers are faulty (because of cyclical and weighting problems);

(2) they are extrapolated too widely, from electric motors in manufacturing to "everything";

(3) they are misused by not allowing for double counting, i.e., these changes are due to other inputs and hence have already been measured;

(4) they are misinterpreted as an increase in input rather than an advancement in knowledge.

We have reviewed our adjustment for relative utilization in Section 4 above. Our revised estimates differ very substantially from our original estimates. In the original estimates we estimated the contribution of utilization to the explanation of growth in total factor productivity at 0.58 percent per year. By reducing the scope of the adjustment to business structures and equipment and by incorporating annual estimates of horsepower or capacity, we have reduced the contribution of utilization to 0.11 percent per year for the period 1950–62. This may be contrasted with Denison's estimate of −0.04 percent per year for the same period.

Denison points out that we do not discuss the "sources" of changes in utilization rates and wonders if there has been some double counting. We do not see why the possibility of a change in machine-hours per year per machine is more mysterious than a change in man-hours per man-year. Obviously, there is a need for an explanation of the sources of such changes and an analysis of the prospects for additional such changes in the future. Although we have not provided such an explanation, we did point out and localize what may be an important source of observed growth in output. An attribution of growth to investment, education, research and development, economies of scale, or capacity utilization is always just the beginning of a relevant line of analysis. But that is as far as one can go within the framework of national income accounting. A more "causal" analysis requires different models, tools, and data.

As to the actual points enumerated by Denison, we see no evidence that the sources of such utilization changes have already been counted in the other inputs. There is no evidence that our rather faulty machinery price deflators have allowed for such improvements in the quality of capital. Nor is there any evidence that this has been already counted in the contribution of labor or inventory input. For example, the ratio of inventories to shipments in manufacturing has remained virtually unchanged between 1947 and 1965.[78]

From our point of view, the main difficulty with the capacity utilization adjustment is that it is not articulated well with our theory and measurement of capital services and their rental prices. We lack an explicit theory of capacity utilization. It is either a disequilibrium phenomenon, or is related to differential costs of working people and machines at different hours of the day and different days of the year. Neither case fits well into the equilibrium, all - prices - are - equalized, framework of national income accounts. One possible basis for such a theory is to make depreciation a function of utilization. Thus, industries where machines worked a higher number of hours per year would have a higher rate of depreciation. In such a world, a mix change such as discussed by Denison would show up as an increase in aggregate capital input, with the weight of industries with higher δ's increasing in the total. And from our point of view, this would be a correct interpretation of the data. An economy that succeeded in recovering its capital in a shorter period would in fact experience a growth in output, and our measure would provide an "explanation" for it.

The issue whether this growth should be attributed to "advances in knowledge" or to increase in "inputs", is ultimately a semantic one. What is important is to know whence it has come, not what its name is. We don't think it very fruitful to put utilization into the "advances in knowledge" category because (a) the latter is already a "residual" category and throwing something more into it will just muddle up its meaning further, and (b) the types of change which are likely to be the sources of the increased rates of utilization, be they institutional or a consequence of changing relative scarcities of machine versus human time, are only very vaguely and probably misleadingly related to the ideas associated with the concept of "advances in knowledge". In any case, our contribution was to isolate and identify a potentially important source of growth. Since we have not really "explained" it, and we agree that this is the important next task, we are unwilling to argue too much over "naming" it. We find it more convenient to work within a broader definition of "input," minimizing thereby the role of the amorphous "residual." But we concede that the same questions can be also asked in a different language.

7.8. Labor input

Our methods for measuring labor input are similar to Denison's, except that Denison reduces the observed income differentials among components of the labor force classified by years of school completed to allow for the correlation between education and "ability." At the same time, Denison also makes an adjustment for the increase in the length of the school year over time. We have made neither of these adjustments and have come out to about the same numbers as Denison, indicating that these two adjustments just about cancel out. Elsewhere one of us has argued that Denison's "ability" adjustment may be too large.[79] Thus, if we had made a smaller ability adjustment and had accepted Denison's "days per school year" adjustment our total labor input would probably grow somewhat faster over most of this period.

Our labor input measure is very similar to Denison's. Careful examination of the issues raised by Denison leads us to the conclusion that our original estimate of labor input can be left unchanged. This estimate has been incorporated into our measure of total factor productivity, but with a relative weight that differs due to changes in our method for allocating noncorporate income between labor and capital. We have also corrected the error of omitting unpaid family workers from our estimates of persons engaged; this leaves the final results unaffected.

7.9. Conclusions and suggestions for further research

We have summarized the differences among our estimates of the rate of growth of total factor productivity for the period 1950–62, based on the results of Christensen and Jorgenson [20], our original estimates [60], and Denison's estimates [28]. At this point it is useful to compare these alternative estimates and to attempt a reconciliation among them; a partial reconciliation is given in table 25. From this comparison it is apparent that our new estimates represent a compromise between our original position and Denison's position. Referring to table 25, we may now summarize our conclusions. From an empirical point of view the greatest differences among our original estimates, our revised estimates, and Denison's estimates are in the adjustment for utilization of resources. Denison estimates that the utilization of resources declines between 1950 and 1962. We estimate that utilization increased, but by considerably less than we originally suggested. The revision in our adjustment for relative utilization accounts for 0.47 percent per year of the total discrepancy of 0.73 percent per year between our original estimate of the rate of growth of total factor productivity and our revised estimate.

From a conceptual point of view the greatest difference among alternative procedures is in the allocation of income from property among its components. Except for our assumption that replacement requirements should be estimated by the double declining balance formula, our estimates of capital stock for each class of assets are very similar to Denison's estimates. Our estimates of capital input differ very substantially from his due to differences in treatment of the tax structure for property income, the use of real rates of return rather than nominal rates for each class of assets, and the use of declining balance

Table 25.—Reconciliation of Alternative Estimates of Growth in Total Factor Productivity, 1950–62

(percent per year)

Denison, adjusted for utilization, his data		1.41
Denison's utilization adjustment	−0.04	
Denison, unadjusted, his data		1.37
Unexplained difference	.07	
Denison, unadjusted, our data		1.44
Capital input:		
Quality change	.30	
Our utilization adjustment	.11	
Jorgenson-Griliches, adjusted, revised		1.03
Revision in utilization adjustment	.47	
Other revisions	.26	
Jorgenson-Griliches, adjusted, original		.30

depreciation and replacement. Part of the unexplained residual between our version of Denison's estimate of total factor productivity and his own is accounted for by his separation of assets among those held by housing, agricultural, and all other sectors of the economy. This separation goes part of the way toward a satisfactory treatment of the tax structure, but should be replaced, in our view, by a breakdown by legal form of organization.

In revising our original computations we have made a number of conservative assumptions and did not correct for some obvious errors in the data where the data base for such adjustments appeared to be too scanty. This is particularly true of the deflators of capital expenditures that we used and of our measure of land input. More research is needed on these and on the magnitude and sources of changes in utilization rates, on capital deterioration and replacement rates, and on the changing characteristics of the labor force.

While better data may decrease further the role of total factor productivity in accounting for the observed growth in output, they are unlikely to eliminate it entirely. It is probably impossible to achieve our original program of accounting for all the sources of growth within the current conventions of national income accounting. But this is no reason to accept the current estimates of total factor productivity as final. Their residual nature makes them intrinsically unsatisfactory for the understanding of actual growth processes and useless for policy purposes.

To make further progress in explaining productivity change will require the extension of such accounts in at least three different directions: (1) allowing rates of return to differ not only by legal form of organization but also by industry and type of asset; (2) incorporating the educational sector into a total economy-wide accounting framework; and (3) constructing measures of research (and other intangible) capital and incorporating them into such productivity accounts.

To allow rates of return to differ among industries and assets would require a much more detailed data base than is currently available and would introduce the notion of disequilibrium (at least in the short and intermediate runs) into such accounts. Such a framework would be consistent with a more general view of sources of growth [10] and would introduce explicitly the changing industrial composition of output as one such source.

In measuring labor input, OBE data on persons engaged should include estimates of the number of unpaid family workers, such as those of Kendrick [61, 62]. Estimates of man-hours for different components of the labor force should be compiled on a basis consistant with data on persons engaged as Kendrick has done. Although Denison [28] has given additional evidence in support of his adjustment of labor input for intensity of effort, a satisfactory treatment of this adjustment requires data on income by hours of work, holding other characteristics of the labor force constant. Until such data become available it may be best to exclude this adjustment from the measure of real labor input incorporated into the national accounts. Quality adjustments for labor input based on such characteristics of the labor force as age, race, sex, occupation, and education should be incorporated into the labor input measure.

The basic accounting framework should also be expanded to incorporate investment in human capital along with investment in physical capital. Investment in human capital is primarily a product of the educational sector, which is not included in the private domestic sector of the economy. In addition to data on education already incorporated into the national accounts, data on physical investment and capital stock in the educational sector would be required for incorporation of investment in human capital into growth accounting.

Another issue for long-term research is the incorporation of research and development into growth accounting. At present research and development expenditures are treated as a current expenditure. Labor and capital employed in research and development activities are commingled with labor and capital used to produce marketable output. The first step in accounting for research and development is to develop data on factors of production devoted to research. The second step is to develop measures of investment in research and development.[81] The final step is to develop data on the stock of accumulated research. A similar accounting problem arises for advertising expenditures, also currently treated as a current expenditure.

Both education and investment in research and development are heavily subsidized in the United States, so that private costs and returns are not equal to social costs and returns. The effects of these subsidies would have to be taken into account in measuring the effects of human capital and accumulated research on productivity in the private sector. If the output of research activities is associated with external benefits in use, these externalities would not be reflected in the private cost of investment in research. Some way must be found to measure these externalities. Once such measures are developed and the growth accounts expanded accordingly, this would result in a significant departure from the conventions of national accounting, more far-reaching than the departures contemplated in our original paper. A new accounting system is required to comprehend the whole range of possible sources of economic growth.

Footnotes

1. Estimates of real capital input are presented in [19]; estimates of total factor productivity are given in [20]. Our original estimates are presented in [47, 60].

2. Christensen and Jorgenson [19], pp. 314–319.

3. Denison [26], pp. 35–37, and Griliches [43], pp. 1414–1417.

4. Accounts are given by Christensen and Jorgenson [20].

5. All references to data from the U.S. national income and product accounts are to *The National Income and Product Accounts of the United States, 1929–1965, Statistical Tables, A Supplement to the Survey of Current Business*, August 1966, henceforward *NIP* [66].

6. Self-employed persons include proprietors and unpaid family workers. The method for imputation of labor compensation of the self-employed that underlies our estimates is discussed in detail by Christensen [18]. Alternative methods for imputation are reviewed by Kravis [63].

7. Kendrick [61, 62]. Office of Business Economics data on nonfarm proprietors and employees are from *NIP* [66], tables 6.4 and 6.6.

8. Christensen and Jorgenson [20] assume that the statistical discrepancy reflects errors in reporting property income rather than labor income.

9. This allocation is described by Christensen and Jorgenson [20], pp. 297–301.

10. A derivation of prices of capital services is given by Hall and Jorgenson [52, 53] for continuous time. Christensen and Jorgenson [19] have converted this formulation to discrete time, added property taxes, and introduced alternative measurements for the tax parameters. Similar formulas have been developed by Coen [21].

11. The perpetual inventory method is discussed by Goldsmith [36] and employed extensively in his *Study of Saving* [38] and more recent studies of U.S. national wealth [34, 35, 37]. This method is also used in the OBE *Capital Goods Study* [49] and in the study of capital stock for the United States by Tice [78].

12. Denison [28], p. 140.

13. Detailed evidence on the quality of the price quotations underlying the WPI is presented by Flueck [32].

14. See Gordon [39] for additional evidence supporting this position.

15. The A.T. & T. structures index uses American Appraisal Company indexes with essentially negligible productivity adjustments since 1955.

16. Gordon's "final Price of Structures" index rises by 11 percent less between 1950 and 1965 than the constant cost 2 deflator. See Gordon [40], table A–1, pp. 427–428. Gordon errs, in a paper published a year later than ours, in failing to notice that the final version of our paper did not incorporate the Bureau of Public Roads index as a deflator but used the more representative but still imperfect OBE constant cost 2 index.

17. The imputation of the value of services from owner-occupied dwellings and structures is imputed by this method in the U.S. national accounts. *NIP* [66], table 7.3.

18. See footnote 6.

19. This division of the private domestic economy follows the U.S. national accounts; see *NIP* [66], table 1.13. Other sectors included in the accounts are government and rest of the world.

20. These data were provided by the Office of Business Economics.

21. Christensen and Jorgenson [20] assume that errors in reporting property income occur mainly in noncorporate business.

22. Christensen and Jorgenson [20] assume that business transfer payments are taken mainly from corporate income.

23. Alternative provisions for the investment tax credit are discussed by Hall and Jorgenson [52].

24. Christensen and Jorgenson [19] assume that no depreciation is taken during the year of acquisition of an asset.

25. Formulas for the present values of depreciation deductions are:

straight-line:

$$\frac{1}{rt}\left[1-\left(\frac{1}{1+r}\right)^{t}\right]$$

sum of the years' digits:

$$\frac{2}{rt}\left[1-\frac{1+r}{r(t+1)}\left(1-\frac{1}{1+r}\right)^{t+1}\right].$$

where r is the discount rate and t is the lifetime of assets allowable for tax purposes. Depreciation practices have adapted to the use of accelerated methods only gradually, as Wales [75] has demonstrated.

26. The appropriate rate of return for this purpose is the long-term expected rate of return; 10 percent is close to the average of corporate after-tax rates of return for the period 1929–67. See Christensen and Jorgenson [19], table 5, pp. 312–313.

27. Griliches [45], pp. 77–78.

28. See footnote 7.

29. See for example [13], p. 7, where it is estimated that the quality of men deteriorated by less than 1 percent over the 10 year period between 1956 and 1966 due to changes in their age distribution.

30.

	Index Numbers; 1958=100			
	Men	Women	Total	Weighted total
1964	107.7	120.8	112.1	110.2
1950	99.1	81.9	93.8	95.7

The weights used were 0.805 for males and 0.195 for females. The share of men in total earnings was 0.81 in 1958 and 0.80 in 1964. These figures imply a −0.13 percent per year decline in the quality of the labor force due to the increase in the female population. Given our average labor share, this would imply a −0.09 percent contribution to the rate of growth of total input. These numbers are taken from [14].

31. "Quality change" in this sense is equivalent to aggregation bias. For further discussion, see Jorgenson and Griliches [60], especially pp. 259–260.

32. Kendrick [62], pp. 252–289, and Solow [70], p. 315.

33. Denison [26], especially pp. 67–72.

34. Denison [26], especially pp. 35–41.

35. Solow [70], p. 315.

36. Kendrick [62], especially pp. 252–289.

37. Denison [25], p. 4.

38. Denison [25], p. 2.

39. See Section 7.5 below for further discussion.

40. Denison [27], fn. 1, p. 2.

41. The absolute contribution of productivity change is discussed by Denison [25], pp. 2–3.

42. See Hall and Jorgenson [52]; see also [53]. We assume here that the decline in efficiency of capital goods with age is geometric so that capital consumption allowances are proportional to capital stock. If decline in efficiency is not geometric, capital consumption allowances are not proportional to capital stock and depreciation is not equal to replacement. Since Denison assumes that decline in efficiency is linear rather than geometric [28, p. 140], serious difficulties arise in preserving internal consistency in his accounts for gross product, net product, factor input, and capital stock. See Section 7.5 below for further discussion.

43. The interpretation of Divisia indexes is discussed by Solow [70], Richter [68], and Jorgenson and Griliches [60].

44. Denison [25], p. 4.

45. Denison [25], p. 4, bases his allocation of noncorporate income on relative shares in the nonfinancial corporate sector. This procedure has the effect of ignoring the impact of the corporate income tax. For further discussion, see Christensen [18].

46. See Denison [25], p. 5.

47. In fact, our revised estimates can be regarded as solving the problem of simultaneously incorporating both property taxation and the corporate income tax posed by Denison as follows:

> For one tax classified as indirect, that on real property, this assumption [that the tax be included in the earnings of capital] may be preferable. Indeed, in the context of considering the effect of taxes on the allocation of resources among sectors of the economy, I have myself suggested that one should not consider the impact of the corporate income tax, which bears only on the corporate sector, without simultaneously considering the property tax, which bears most heavily on the principal noncorporate sectors of the private economy: housing and farming [25, p. 5].

48. Denison [25], pp. 6–13.

49. Denison [25], p. 8.

50. Denison [25], p. 8, suggests adjusting the weight of land, but not that of other capital, for inflation. His actual procedure [26, 28] for allocating property income ignores the effects of inflation for all assets. Denison [25], p. 8, argues that:

> Their [our] idea is that current asset values are proportional to . . . the discounted value of the anticipated stream of earnings and capital gains . . . .

He then states that prices of depreciable assets

> . . . are firmly anchored to the present price level and present production costs of capital goods and are not affected by capital gains.

Actually, the contradiction between our view and his is only apparent. From the point of view of producers of capital goods the prices are anchored to present production costs. From the point of view of purchasers of capital goods these prices are related to the discounted value of future earnings, including capital gains or losses. Thus prices are simultaneously anchored to the current price level and to anticipations of future earnings.

51. Denison [25], pp. 8, 13, acknowledges the possibility that his results could be improved by taking capital gains into account in measuring earnings from land.

52. Denison [25], p. 13.

53. Jorgenson and Griliches [60], p. 257. See Kendrick [61, 62].

54. Denison [25], p. 13.

55. Denison [28], p. 140.

56. Denison [28], p. 140.

57. Denison [28], p. 14.

58. Denison [28], p. 351.

59. Denison [28], p. 14.

60. Denison [26], pp. 112–113.

61. Denison [28], p. 140.

62. Denison [28], p. 351.

63. Hickman [54], pp. 223–248; Hall and Jorgenson [52], pp. 28–31. Many other references could be given. Geometrically declining efficiency is the standard assumption in econometric studies of investment behavior.

64. Meyer and Kuh [64], pp. 91–94.

65. Cagan [17], pp. 222–226; Griliches [42], pp. 197–200; Wykoff [76], pp. 171–172.

66. Hall [51], pp. 19–20.

67. Griliches [41], pp. 121–123 and 129–131.

68. Jorgenson and Griliches [60], pp. 259–260; see also [44].

69. Jorgenson and Griliches [60], p. 260.

70. See Solow [69, 71]; for an interpretation of the resulting measure of capital input, see Jorgenson [59].

71. Denison [25], p. 26.

72. For a detailed discussion, see Christensen and Jorgenson [19], p. 296.

73. Our calculations are based on data from Goldsmith [35], table A–13:

Category of private land	In constant prices (1947–49=100) 1945 (1)	1958 (2)	Rate of change per year 1945–58 (3)	Average (1945–58) relative weight in total value of private land (4)
Agricultural	53.6	52.9	−0.16	0.40
Residential	31.3	44.6	2.77	.21
Nonresidential	47.7	64.6	2.37	.33
Forests	6.4	6.9	.60	.06

NOTE.—Rate of growth of private stock of land per year=Σ(column 3×column 4)=1.38.

74. Denison [19] employs OBE estimates of inventory stocks [25], p. 13; we have employed the same estimates of inventory stocks. We also incorporate estimates of stocks of depreciable assets from the OBE Capital Goods Study [49]. Although Denison did not employ these estimates, he indicates that:

> Had the OBE study been completed, I would have used OBE capital stock series based on Bulletin F lives, on the use of the Winfrey distribution for retirements, and on the use of the OBE "price deflation II" [25, p. 14].

This accords with our estimates except for the use of the Winfrey distribution.

75. See [49].

76. Denison [25], pp. 12–14.

77. Denison [25], p. 16.

78. There is also some confusion about the measurement of marginal contributions in some of Denison's examples. These examples seem to imply that if higher skill workers are required to run new machines, the contribution of such machines cannot be measured separately and is already included in the contribution of labor input. But this is clearly wrong.

79. Griliches [45] and [48].

80. See Johnson [57] for an outline of a similar position.

81. See Griliches [46] for further discussion of this topic and for some order of magnitude estimates.

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By EDWARD F. DENISON

Final Comments

I. Changes and Clarifications

Dale Jorgenson and Zvi Griliches amend and clarify their views in the preceding article [24]. I am pleased that revisions bring their estimates close to mine, and appreciate their statement that my critique of their earlier estimates was helpful.

The reappearance of productivity change

Jorgenson and Griliches abandon or greatly mute the main point of their earlier article. They had asserted that analysts who preceded them were wrong to attribute a substantial part of the growth of United States output to rising productivity. On the contrary, Jorgenson and Griliches stated, there has been little or no change in productivity. The conflicting results obtained by the rest of us stemmed from procedural errors in measurement which they "weeded out," and these errors had caused us to misinterpret the very fundamentals of economic growth.

The basis for their claim was their own estimate that real GNP per unit of input increased only 0.10 percent a year in the private domestic economy from 1945 to 1965 [18]. This was supported by previous research in which they had almost eliminated productivity increase over the whole period since 1929 [15]. They suggested that still more precise accounting for inputs would probably show that there had been no change at all in productivity.

Their series showed that from 1950 to 1962 rising productivity contributed 0.30 percentage points to the growth rate of private domestic GNP. My estimates for the same period implied 1.38 points.[1] My SURVEY article investigated the reasons for the discrepancy, concluded their series was wrong, and showed why [19].[2] They have now accepted much of my criticism. As against their former 0.30, their new estimate appears to be about 1.14.[3]

Their revision comes chiefly from (1) discarding most of their capital utilization adjustment and (2) eliminating most sales and excise taxes from their estimates of the earnings of capital. Some of the other errors (as in their measurement of inventories) have been corrected. Their new figure, though in my opinion still too low, is 83 percent of mine, so the "disappearance" of productivity change has vanished. The remaining difference of 17 percent between our estimates raises no question about the fundamentals of economic growth.

Jorgenson and Griliches now conclude (p. 89) that "While better data may decrease further the role of total factor productivity in accounting for the observed growth in output, they are unlikely to eliminate it entirely." This is a reversal of their original position. But one might have hoped for a less equivocal statement. Better data may always raise or lower an estimate. But this sentence implies an undocumented belief that they would probably *reduce* the estimated growth in total factor productivity; that this reduction would not be achieved by a mere reclassification of growth sources from productivity to input; and that it remains possible, if unlikely, that all the advances in technology and managerial knowledge that we have observed, the expansion of markets, shifts of surplus labor from farming, etc., have done nothing to raise productivity.

I do not share these beliefs. The idea that productivity may not have changed at all is as farfetched as ever. Moreover, better data are as likely to raise as to lower estimates of productivity gain. A

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Very helpful comments from George Jaszi and T. K. Rymes are gratefully acknowledged. Neither shares responsibility for views expressed or any errors I may have committed.

1. This was after adjustment, for comparability with their estimate, of my figure of 1.37 points for the contribution of output per unit of input to the growth rate of total national income.

2. My brief but similar comments on their previous article had been disregarded [16].

3. They show 1.03 in their table 24, which refers to an output series whose scope has been changed by addition of a large imputation for depreciation of and imputed rent on consumer durables. All of the amount imputed is necessarily counted as a contribution of capital input. The addition to the scope of the output measure much reduces the productivity estimate when, as in this figure, it is expressed as a growth rate or contribution to the growth rate of total output. They describe the need to adjust the figure for comparability with their earlier estimates or mine, but their table 25, which compares the three estimates, surprisingly repeats the 1.43 figure so cannot have been adjusted. They give insufficient data to adjust precisely, but an adjustment to 1.14 for comparability appears conservative.

careful reworking of my own estimates is, in fact, yielding slightly higher figures for the contribution of output per unit of input than those obtained previously, which were already above the amended figures of Jorgenson and Griliches.

Clarification of Jorgenson-Griliches treatment of unmeasured quality change in capital goods

I welcome the clarification by Jorgenson and Griliches of their views concerning "unmeasured quality change" in capital goods. Such quality change consists of improvements in the design of capital goods that raise their marginal products relative to their costs.

All readers of the original article by Jorgenson and Griliches whom I encountered were reluctant to attribute to them the view that advances in knowledge, economies of scale, and reallocation of resources together have contributed only trivially, if at all, to longrun growth because this view is alien to common sense and contradictory of previous research. They believed the Jorgenson-Griliches finding of almost no productivity change must derive from use of a different classification.[4] Most thought, not without encouragement from the wording of the article [18, especially pp. 36-37], that one aspect of this reclassification was the transfer of some of the contribution of advances in knowledge from productivity to input by counting unmeasured quality improvement in capital goods as an increase in capital input. My article pointed out that nothing in their statistical procedures would produce this result. Moreover, it pointed out, it was not really clear from their text whether or not Jorgenson and Griliches even thought they had made such a transfer. Their current article agrees that they made no such transfer, and states that they did not think they had done so. They agree that no part of the difference between either their earlier or present estimates and mine is caused by a different treatment of unmeasured quality change. This is a welcome clarification.

Desired treatment of unmeasured quality change

But what Jorgenson and Griliches would *like* to do about quality change that is not measured by present procedures still requires discussion. Although they indicate that their view of embodiment is the same as mine (p. 87), it is not clear whether this means that their view of the appropriate treatment of unmeasured quality change is the same. To clarify this point it is necessary to retrace old ground once more.

Although present measures of capital investment, and hence of capital stock, in constant prices do not conform exactly to any definition because good price data are scarce, they do have a general characteristic which can be described and illustrated and is the characteristic under discussion.

Suppose that in Year 1 a certain kind of factory building costs \$1 million (inclusive of all costs including the return to equity capital of builders and suppliers) and that it also sells for \$1 million. By the time some subsequent Year 2 arrives, a certain architect, Mr. Smith, has devised a new factory layout that is more efficient, and new factories are now constructed in accordance with his design. Factories of the old design may not be built at all in Year 2, but they could be built and sold for \$1½ million; because of inflation their cost is higher than it was in Year 1. The new factory costs and sells for \$2 million in Year 2.

The price index for factories in Year 2 (Year 1=100) that is used in deflation will (barring measurement errors) be 150 (\$1½ million ÷ \$1 million), and this is the crucial number. Deflating current dollar expenditures by the price index yields values in constant prices of Year 1 of \$1 million for an old-type factory and \$1⅓ million for a new-type factory. These constant-price values for the two types of factories are, of course, used in all years in which they are produced. The new-type factory is thus always counted as the equivalent of 1⅓ old-type factories; this is the number of old-type factories that could be built in Year 2 with the resources actually devoted to building each new-type factory in Year 2, because \$2 million is 1⅓ times as much as \$1½ million. The difference between 1 and 1⅓ is measured quality change. Capital stock series in constant prices are constructed by cumulating past investment in constant prices, so new-type factories are counted as 1⅓ times as much capital as old-type ones in capital stock series too. The marginal product of a new-type factory after it is in service is more than 1⅓ times as great as that of an old-type factory because of the improved layout that Mr. Smith has devised. We can infer that this is so because buyers' preference for the new type means they believe the ratio of marginal product to cost is higher for the new-type factory than for the old. But we have no way of knowing by how much this ratio exceeds 1⅓. If factories were rented, the rent on a new-type factory would also be more (by the same unknown amount) than 1⅓ times the rent on an old-type factory, if neither had deteriorated from use, because the relative rental values would be proportional to relative marginal products. The difference between the cost ratio of 1⅓ and the unknown but higher marginal product ratio is the "unmeasured quality change" that has occurred in factories. The result is similar, because of the nature of price data used in deflation, for producers' durable goods (and, indeed, for consumers' goods if "marginal utility" is substituted for "marginal product" in the description).

In my view, often stated, (1) it is impossible to substitute marginal products for costs in equating capital goods of different vintages because unmeasured quality change cannot be measured, and (2) for growth analysis it is better to equate (weight) unused

4. When Jorgenson and Griliches first suggested that a complete accounting would eliminate changes in output per unit of input, I *myself* wondered whether they might somehow consider that anything measured directly becomes an "input," which would make output per unit of input a synonym for the "residual." The "residual" in growth analysis obviously and by definition would disappear if the effects of changes in all determinants of output—whether components of output per unit of input or of total input—could be and were directly and precisely measured. Even in their present article, passages on pages 85 and 89 seem to use "output per unit of input" and the "residual" interchangeably and thus to support the original suspicion. But their explicit disavowal of this interpretation of the earlier article and the general thrust of their present article indicate that when they say output per unit of input (or total factor productivity) they mean this, and not the residual.

capital goods of the types represented in different vintages by their actual or hypothetical relative cost at a common date than by marginal products. With this procedure, to which actual "conventionally measured" data approximately correspond, unmeasured quality improvement does not raise capital input when earlier vintages are replaced by later ones. Gains achieved from designing better capital goods are counted as contributions of advances in knowledge—in the previous example, as the contribution of Mr. Smith's discovery of an improved factory layout.

A theoretical alternative would count capital goods of a later vintage which embody unmeasured quality improvements as more capital relative to those of an earlier vintage by substituting the ratio of their marginal products for the ratio of their costs at a common date as weights to combine them. If it could be implemented, this procedure would cause the capital stock in constant prices and hence capital input to rise more over time than the present procedure, and would transfer the the gains provided by improved design of capital goods from advances in knowledge to capital. This would eliminate the possibility of a rise in the efficiency of capital and would destroy the possibility of analyzing advances in knowledge as a separate source of growth.

Jorgenson and Griliches repeat in the present article the statement that was the original cause of confusion about this whole subject: that they would like to weight capital goods of different vintages which are in simultaneous use by their relative marginal products if services prices were available from which relative marginal products could be inferred (p. 87). Service prices per dollar of conventionally measured gross stock would be lower for older than for newer vintages not only because they are older and their performance may have deteriorated more from the time they were new (which everyone agrees should be taken into account in measuring capital input) but also because newer vintages incorporate design improvements. What would this procedure mean for the measurement of capital input? Presumably, Jorgenson and Griliches would change the input of any one vintage during its service life only to allow for physical deterioration occurring in the services provided as time passes. Apart from this, each vintage would be the same amount of input so long as it was in use. Because of design improvement, each successive vintage would be counted as more input, relative to a vintage remaining in use, than the preceding vintage when it had been in the same physical condition. Hence, replacement of each vintage by a later vintage would raise capital input. The procedure would therefore raise the growth rate of the capital stock in constant prices (and hence capital input) relative to the conventional capital stock measure, and change the classification of growth sources by transferring from advances in knowledge to capital the output effects of improvements in the design of capital goods.[5] It is not clear whether Jorgenson and Griliches deny that this is so (a position that previous writing by Jorgenson [14] may imply) or whether they mean that they *wish* to make such a transfer.

To try to avoid further confusion, I must comment upon the following sentence from Jorgenson and Griliches (p. 87): "If it were possible to implement our original suggestion that different vintages of capital goods be weighted in measuring capital input by their marginal products, this would not have the effect of incorporating 'embodied' technical progress, as Denison suggests." The term "embodied technical progress" has often been used with a very broad though rather vague meaning to cover the *total* effects on productivity of any change in processes of production that requires a change in the physical attributes of a capital good—no matter how trivial the change in the capital good may be, and regardless of whether or not the new knowledge that is being introduced stems from or has any relationship to knowledge about capital goods design. Jorgenson and I [12, 14, and elsewhere] both indicated years ago that we saw little or no value to this concept nor possibility of obtaining estimates conforming to it, and had no wish to adopt it. This is not a source of disagreement between us, nor is it what I have been discussing. I have been discussing only embodiment into the capital input measure of the difference between the growth rates of capital stock when different vintages are equated by (a) marginal products at a common date, and (b) cost at a common date, and the resulting transfer, from the contribution made to the growth rate of output by advances in knowledge to that of capital, of this difference times the weight in total input assigned to structures and equipment. My view, to repeat once more, is that this transfer (1) cannot be made and (2) would be undesirable in any case because it would yield a less useful classification of growth sources; what is really the contribution of advances in knowledge would be counted as a contribution of capital [19, p. 27; 23]. Jorgenson and Griliches (1) agree that this transfer cannot be made, at least for most goods at the present time, but (2) whether they would like to make it I still do not know.

Clarification of views on inclusion of depreciation in weights

A more complete clarification concerns the Jorgenson-Griliches view of the appropriate treatment of depreciation when earnings are used to weight labor, capital, and land. They had stated vigorously that other analysts erred in obtaining earnings weights by using property earnings measured net, rather than gross, of depreciation. On at least three occasions they attacked John Kendrick, specifically, for using net earnings. They made no distinction between analyses of gross and net product. Kendrick's valuable analyses of productivity change have concentrated on growth of net product, but he has also derived gross product as an incidental by-product of his analysis.

5. This result would be avoided only if the input (in constant prices) of any vintage were made to decline each year within its service life to reflect not only deterioration but also obsolescence resulting from the availability of better goods. No intention to use this novel procedure can be inferred from their writing, and the procedure could not be implemented by use of service prices because, even if they existed, service prices would not permit effects of obsolescence on service price differentials to be distinguished from those of wear and tear.

My article stated that net earnings should be used to analyze net product, and gross earnings to analyze gross product.[6] Thinking only of Kendrick's net product analysis, I defended his use of net earnings for weights. Jorgenson and Griliches now state that their criticism of Kendrick referred only to his gross product analysis. Thus we agree on this important point.

II. New Estimates

Time passes. Much of the new Jorgenson-Griliches article is devoted to the reproduction, description, and defense of estimates that were recently published elsewhere by Christensen and Jorgenson, are here endorsed by Griliches, and are presented as replacements for the previous Jorgenson-Griliches estimates. I have also been reworking and extending my estimates, and have introduced numerous refinements in data and technique. A later publication will present and describe them.

I shall neither undertake here a general examination of the new Christensen-Jorgenson estimates and the Jorgenson-Griliches discussion of them nor describe the changes being made in my own procedures. It is unnecessary because my views as expressed in the previous Survey of Current Business article have not changed and need not, in general, be reiterated.[7] Alterations being made in my procedures are consistent with those expressed there. Any sufficiently diligent and perspicacious reader can discover the extent, which is substantial, that Christensen-Jorgenson have changed the Jorgenson-Griliches procedures to meet my objections. I shall, however, offer brief observations on three aspects of the new estimates and their discussion, and then turn in part IV to an extended discussion of various aspects of a general topic which permeates their article.

III. Miscellaneous Brief Comments

This section comments upon three unrelated aspects of the new article by Jorgenson and Griliches.

Statistical errors

Some of the simple statistical errors in the original Jorgenson-Griliches estimates have now been weeded out, but the procedure that Christensen and Jorgenson use to obtain private GNP in constant prices by their definition (p. 68) contains an odd new error that is very large. From OBE's estimates of GNP in constant prices one would expect them to subtract OBE's general government and rest-of-the-world GNP in constant prices and an estimate for government enterprises. Instead, from OBE's total GNP in constant prices they subtract estimates for general government, government enterprise, and rest-of-the-world GNP that they obtain by dividing OBE's current dollar figures for government, government enterprise, and rest-of-the-world GNP by the average price of all services in the GNP. Consequently, they take out of OBE's GNP in constant prices numbers for general government and rest-of-the-world GNP that are quite different from those that OBE has put in, and the difference becomes part of their private GNP series. It causes them to understate the increase in private GNP in 1958 prices by $5 billion from 1950 to 1962 and by $12 billion from 1948 to 1967, and to understate productivity growth accordingly.

Change in classification of gains from reallocation of resources

The new Christensen-Jorgenson estimates transfer some of the effects of improving or worsening the allocation of resources from productivity to input. Other procedures that Jorgenson and Griliches recommend would go much further in this direction. They do not note these classification effects.

Christensen and Jorgenson separate corporate assets of each type from noncorporate assets, separate farm from nonfarm inventories, and measure each component as a separate input with its own weight (p. 69). The effect is to transfer from output per unit of input to total input gains or losses in output that result from an improved or worsened distribution of each type of capital and of land between corporate and noncorporate use, and in the case of inventories between farm and nonfarm use. Jorgenson and Griliches recommend (pp. 67, 77) treating labor in each occupation and region as a separate input in measuring labor input, although they have not actually done so. This would transfer from output per unit of input to total input gains resulting from an improved allocation of labor among occupations or regions (with no change in the personal attributes of workers). Because of the close correspondence of occupations and industry in the case of farming, gains from shifting labor from farm to nonfarm activities would also be transferred. They also suggest counting as separate inputs different types of investment, and investment in different industries in which rates of return vary; in this case they say the results will help in "explaining" productivity change (rather than that the differences in earnings should be "reflected" in input), but the difference in wording appears to be accidental.

If the distinction between output

6. Alternatively, I noted, if the opposite were done depreciation could be treated as a separate deduction from, or addition to, output that is ascribable to capital.

7. Among many others which I shall not mention again, these include views on long-term changes in capital utilization and the measurement of capital gains in the Jorgenson-Griliches and Christensen-Jorgenson estimates.

growth achieved by an increase in total factor input and output growth achieved by an increase in total factor productivity has any meaning, output gains or losses resulting from the shift of an input from one use to another surely belong in the productivity series. Hence, the changes in input measurement that Jorgenson and Griliches make and suggest are inappropriate. The proper course, in my opinion, is to retain these gains and losses in productivity, but to try to isolate them as a separate productivity component.[8]

Additional duplication from imputations

Objections to the use of gross output in growth analysis become stronger if imputations for consumer durables or human capital are added to the scope of output. The reason I consider even the OBE version of GNP to be an unsatisfactory and uninteresting output measure for growth analysis is that it is a duplicated measure and there is no reason to wish to maximize its value (relative to real costs incurred). Some economists whose judgment I respect nevertheless prefer it on the grounds that it is so difficult to measure capital consumption that GNP may yield a better index than NNP of the growth rate of net output itself. I believe this is incorrect; but even if it were correct, use of GNP leads to wrong conclusions as to the increases in net output that result from adding to capital.

Because no basic principle underlies the amount of duplication in GNP, it is always easy to raise its value by increasing the amount of duplication. By introducing into GNP an imputation for the gross return on consumer durables, Jorgenson and Griliches more than double the value placed upon them. Most of the addition is for depreciation; consumer durables are quite short-lived so they depreciate quickly. This addition greatly increases the duplication already present in the OBE version of GNP.

In contrast to business depreciation, which is subtracted from GNP to obtain NNP, this imputed depreciation on consumer durables must be added to NNP to obtain GNP. If there were merit to the statistical case for using GNP with its present coverage because depreciation is hard to measure, this would argue for *not* adding imputed depreciation on consumer durables.

One effect on growth analysis of the imputation for consumer durables is to change the growth rate of GNP, unless the imputation moves like the rest of GNP. But the main effect is to raise greatly the apparent contribution of capital to the growth rate of output and to lower that of productivity and labor, because all of the absolute increase from one date to another in the imputed depreciation on (as well as the net return to) consumer durables is counted as a contribution of capital. The resulting estimates of contribituons to the growth rate refer to an output measure for which I can see no use. The imputation would not seem to advance the "measurement of total factor productivity from the perspective provided by the economic theory of production," the avowed purpose of Jorgenson and Griliches in preparing their new output measure (p. 65), nor correspond to "the value of output and factor input from the point of view of the producer" (p. 67).[9] If "human capital" is measured as Jorgenson and Griliches recommend (p. 90) I hope it too will not be entered twice.

IV. Capital Input, Depreciation, and Use of Asset Values in Deriving Weights

The Jorgenson-Griliches discussion of the measurement of capital input, net output, net property earnings for use in weights, and the relationships among these series calls for more extended comment, and the remainder of my reply is devoted to these topics.

Jorgenson and Griliches unfortunately introduce into their discussion a false identity and an erroneous description of my depreciation series which greatly confuse the issues and which also make their discussion of the remaining matters obscure. I must deal with these topics before I take up real issues, and the first two of the six subtopics in this section try to clear away this underbrush.

The third subtopic, the most substantive, reexamines the time pattern of capital input, which Jorgenson and Griliches appraise very differently than I do.

The last three subtopics consider the best methods of obtaining depreciation for net product and net earnings estimation, but they are introduced mainly as a response to sweeping and erroneous claims by Jorgenson and Griliches that my estimates are inconsistent in several respects and their own estimates are free of such inconsistencies because they use the double declining balance formula to measure everything. Their specific charges are that (1) the depreciation series I use to obtain net product is inconsistent with my capital input series, that (2) the depreciation series I use to obtain the net earnings of capital and land (which are used to weight these inputs with labor) is inconsistent both with my series for capital input and with the depreciation series I use to obtain net product, and that (3) the series for net stock I use to allocate the total weight of capital and land among components is inconsistent with my capital input series.

The format of a reply to this article by Jorgenson and Griliches is rather inconvenient for a general discussion of the difficult problems involved in handling capital in the measurement of output and input. It not only introduces terminological problems but also forces me to concentrate upon the matters raised by their article, some of which would arise in no other context, at the cost of complicating and restricting discussion of subjects of greater interest and importance. One aspect

8. See [25] for a more complete discussion of the classification of the effects of reallocation.

9. Use of GNP is sometimes advocated for short-term employment analysis. Imputed depreciation certainly creates no employment so its inclusion worsens the GNP measure for this use too.

of the difficulty is that the Jorgenson-Griliches advocacy of use in empirical estimation of the double declining balance formula to measure everything is uncommon if not unique. Curiously, just when Griliches and Jorgenson were first introducing this unusual (and, I believe, quite unacceptable) convention into their growth analysis [15], Griliches himself was discussing related matters more realistically [11, especially pp. 118-25], plotting (for tractors) different curves for the market values of capital goods and for their services, and examining the relevance for different measures of discounting, deterioration, and obsolescence. Use of that article as a starting point might have made for a less complex discussion.

An accounting identity?

Jorgenson and Griliches state as a general principle that "the value of total product is equal to the value of total factor input as an accounting identity" (p. 65) and, again, that "for any concept of gross product the fundamental accounting identity for productivity measurement is that the value of output is equal to the value of input" (p. 67). Their algebraic presentation starts with this supposed identity and long sections of their paper are based upon it. They criticize my methodology because, they say, I violate it.

In fact, no such identity exists except in one special case: a current-dollar series for gross or net national product valued at factor cost.

National accountants recognize market price and factor cost as the two main alternative ways of valuing the components of output, and the new United Nations system recognizes still others. In their original article Jorgenson and Griliches valued output at market prices. Reliance upon their nonexistent "identity" misled them into counting all indirect business taxes and some other assorted items as earnings of capital and land, a mistake they have partially remedied in their new estimates.[10] The identity does and can hold in a current price output measure only if output is valued at factor cost; in that series it must hold because the value placed upon each unit of output is, by definition, the amounts earned by the factors in providing it.

But current price measures have little to do with "productivity measurement," and the identity does not hold in constant prices even at factor cost—unless one abolishes the concept of productivity change. Productivity change is precisely a measure of the degree to which the identity does not hold.[11] There is no such accounting relationship between input and output at constant prices by any method of valuation. The two must be defined and calculated independently.

Christensen and Jorgenson introduce a new valuation for the components of output which they call "gross value added from the point of view of the producer" [22]; similar language is used here on p. 82 and thereafter. Components of gross output are given a value which in current prices is equal to their factor cost plus the following items listed on p. 67:

—The statistical discrepancy in the national income and product account: —$4.5 billion in 1970, but often positive, and erratic from year to year;

—Motor vehicle licenses: $1.6 billion in 1970;

—Property taxes: $35.4 billion in 1970;

—"Other" State and local indirect business taxes: $6.9 billion in 1970, of which, in billions, $3.1 was State selective sales taxes; $1.3 miscellaneous corporate, business, and occupational licenses; $0.7 severance taxes; $0.3 stock and other transfer taxes; and $1.5 miscellaneous local licenses and taxes;

—Business transfer payments: $3.9 billion in 1970, of which, in billions, $1.6 was auto liability payments for personal injury; $1.1 bad debts; $1.0 corporate contributions to nonprofit organizations; and $0.1 unrecoverable thefts.[12]

Given this method of valuing end products, one might wonder how Jorgenson, Christensen, and Griliches can make their own estimates satisfy the "accounting identity" they adduce, even in current prices. The answer is easy. By counting whatever is not labor earnings as capital earnings (p. 68), they simply add all the items not in factor cost to the earnings of capital and land as well as to the value of output. Jorgenson and Griliches give no real explanation of why they adopt this particular method of valuing output. A possible justification, which they do not suggest, would be that the new valuation is meant to provide better estimates of the value of output at factor cost and of the earnings of capital and land than those which emerge from the standard national accounting procedures. There is a minority view that property taxes should be included in factor cost, so this position might be argued with respect to this one large item or part of it. But one must hold extraordinary views indeed as to the source of the statistical discrepancy and as to the incidence of most of the other tax items and transfer payments to support their inclusion in property earnings.

Language problems and a misstatement

Is it really acceptable for Jorgenson and Griliches to allow their penchant for shocking statements to be carried to the extent of incorrectly describing

10. The mistake, of course, was that there is no identity, not that there is some defect in market prices. Market prices provide perfectly sensible valuations of output, and I have shown [19, p. 4] that is it perfectly possible to analyze the growth of national product at market prices in a sensible and consistent way.

11. The Jorgenson-Griliches paper does contain (p. 79) the following sentence: "Total factor productivity is defined as the ratio of real product to real factor input, *or equivalently, as the ratio of the price of factor input to the product price* [italics mine]." The italicized portion may have been included to protect their assertion of an identity; their discussion on page 82, where they say productivity is equal to the difference between changes in the prices of output and input, each multiplied by the corresponding quantity, supports this inference. Viewing the ratio as a difference in the price movements of input and output would make the identity hold in constant prices by making input definitionally equal to output, that is by measuring inputs over time as the product of their quantities and marginal products. This is the definition they have consistently denied using.

12. I ignore here their imputation for consumers' durables and capital owned by institutions, and their deletion of government enterprises, because these raise issues of scope rather than of valuation.

other people's procedures, considering that there is a danger they might be believed? In this article they make with no qualification a statement that is false in terms of the definitions used for generations by accountants, economists, businessmen, the Department of Commerce, and dictionary writers alike: "Denison measures net national product as gross product less replacement; the correct definition is gross product less depreciation" (p. 65).[13] Jorgenson and Griliches know very well that what I deduct is an estimate of depreciation computed by the straight-line method. Whether this is the best method of estimating depreciation is debatable, but I never before have heard it denied that it *is* an estimate of depreciation.

"Replacement" has usually been used in this field with its ordinary meaning, to distinguish between actual new gross investment that is made for the purpose of replacing capacity to be discarded and gross investment that is made for modernization, to expand capacity, or to produce new products [e.g., 4, p. 36; 5, p. 9]. It has nothing to do with my depreciation estimates.

Jorgenson and Griliches mean something else by "replacement." The meaning they give it has nothing to do with my net product estimates either, but it does confuse any attempt to exchange ideas. In their special language, replacement occurs even if there is no gross investment at all (see the formula on p. 69)! By replacement they seem to mean the decline from the beginning to the end of a period in the input of, or current services provided by, the capital goods that were present at the beginning of the period—a decline that may result either from discarding or from deterioration in the performance of goods not discarded as a result of wear and tear. This could be described as the amount of capital input that would have to be replaced through gross investment if capital input were to be kept unchanged from the beginning to the end of a period (and hence output, in the absence of any other change). It is obvious that "replacement" in this sense is not the same as capital consumption (or depreciation, or the amount of gross investment that would be needed to keep capital intact). Consequently, it is not the proper amount to deduct to obtain net product, and it is not the amount I do deduct. Capital input from the wonderful one-hoss shay did not decline from its 70th to its 71st year, so "replacement" in this sense was zero, but there was nevertheless capital consumption because its remaining period of usefulness was reduced by one year. My procedure, of course, would make a deduction; I do not deduct "replacement" in their sense, so their statement that I "deduct replacement" is incorrect even by their special definition.

Jorgenson and Griliches claim to have one series that simultaneously measures *both* the decline in capital input *and* capital consumption. "Replacement" in their terminology can perhaps be defined then as that magnitude which has the magic property of being equal to two things which are not equal to each other.

Capital input

I turn now to a more substantive topic, the timing of *capital input*. The necessity for this discussion arises mainly because Jorgenson and Griliches continue to measure capital input in a way I regard as wholly implausible and recommend their procedure to me. But it is also needed for my subsequent discussion of their claim that I use inconsistent procedures and that their own estimates are free of such sins.

The discussion of this and the following subtopics will inevitably convey a greatly exaggerated impression of the sensitivity of actual growth analyses of real economies to the choice of series and procedures. In most periods actual results are not sensitive to the choices made for measurement of capital input and net product. But one cannot be indifferent among them.

For growth analysis, a series for the input of a structure or producer's durable good is meant to measure the change that occurs each year in its ability to contribute to annual production. This is not the same as the change in its money earnings (or service price) even if the prices of output and of capital goods do not change. As a capital good grows older its earnings may be reduced by competition from newer types of capital goods which appear on the market, the cause of most obsolescence.[14] Such obsolescence is simply the counterpart of "unmeasured" quality change in capital goods. The appearance of better goods does not reduce the ability of existing goods to produce and therefore should not be allowed to affect capital input.[15]

Series that are used to measure the total input of structures and equipment (jointly or separately) are explicitly or implicitly a weighted average of estimates for each "vintage" of each type of capital good. The implications of the Jorgenson-Griliches procedure and mine can therefore be compared by contrasting the results we obtain for one vintage of one type of capital good.

Let 100 units of some type of nonresidential structure or equipment, costing $1,000 per unit, enter the stock at the middle of some year.[16] Suppose that with normal use and maintenance these goods would have an average service life of, say, 30 years if no better capital goods were designed in the interim, but that because of obsolescence it will actually be profitable to scrap them after an average of 20 years so that 20 years is the observed average service life. It is common for these two figures to differ; surveys (as well as observa-

13. They even repeat the statement (as on pp. 83, 86)! They also say (p. 87) that my net stock is "net of replacement rather than net of depreciation" and cite in evidence a page from my writing which says unambiguously "the estimates based on . . . straight-line depreciation were selected."

14. Obsolescence may also occur because of a decline in demand for the products a capital good is best able to produce or a change in the location that is best for its installation. I interpret this type of obsolescence as impairing its ability to contribute to annual production, and thus as properly reflected in capital input, but I believe this type to be of relatively minor importance. For brevity, I shall henceforth exclude it when I refer to obsolescence.

15. I presume Jorgenson and Griliches would agree with this statement so long as it is clear that in their case I (1) refer to what they call in their table 11 "potential capital input," so that their utilization adjustment is not at issue, and (2) refer to their present capital input estimates which do not incorporate unmeasured quality change. I need not speculate on their views as to the treatment of obsolescence if unmeasured quality change were to be incorporated.

16. The OBE capital stock estimates are based on the simplifying assumption that each year's new investment is made at midyear. The series shown in chart 1 follow OBE procedures. Jorgenson and Griliches evidently assume that all investment is made at the end of the year (see their footnote 20).

tion) show obsolescence of existing capital goods by technical change to be a common reason for discarding them and incurring the expense of new gross investment [e.g., 4, p. 36]. In our actual estimates Jorgenson-Griliches and I use the same numbers for the figures corresponding to the 20-year period and make no use of figures corresponding to the 30-year period because none are available. But the difference between the two should be kept in mind in evaluating the reasonableness of alternative methods of measuring capital input.

Suppose also that when the goods are discarded they will have no scrap value. Suppose, finally, that goods identical to those introduced in Year 0 (as well as improved ones, after the initial year) could be bought at the same price throughout the service life of these goods, so that historical cost, current cost, and conventionally measured constant cost value are all the same. These assumptions simplify the example and discussion without affecting the issues. Chart 1(A) shows the series we would each obtain for the capital input provided by these goods over time. It is obvious that I estimate the decline in input to be far less rapid than do Jorgenson and Griliches.

The Denison series is estimated by calculating a weighted average of gross stock (weighted 3) and net stock (weighted 1) when these series are computed by use of the Winfrey distribution of retirements around the mean service life and the net stock is computed by use of straight-line depreciation.[17] The Winfrey distribution avoids the unrealistic assumption that the entire vintage is discarded on the same date. The distribution of discards that it imposes is indicated by the gross stock series shown in chart 1(C), which corresponds to the numbers of goods remaining in the stock at each date.[18] My procedure of weighting gross and net stock is simply a convenient way to obtain a capital input series that moves in a way I regard as reasonable. So long as all of the goods remain in the stock the input series declines moderately; this decline is intended to reflect any decline in performance and rising expenditures for repairs and maintenance (which must be deducted to arrive at the contribution of capital goods to GNP or NNP whether they are incurred by the user or by the seller under a guarantee). The faster decline starting in the ninth year marks the beginning of the complete discarding of some of the 100 capital goods as estimated by the Winfrey distribution, and the subsequent changes in the rate of decline reflect the time scatter of discards. When half the average service life is exhausted, 99 percent of the goods are estimated still to be in use and capital input is estimated to be 87 percent of its amount at the beginning. When the average service life of 20 years (which is less than the average physical life) is reached and half the goods remain in the stock, capital input is 39 percent of its amount at the start.

No doubt the correct time pattern for the change in total capital input for a vintage varies among types of capital goods, but this seems to me a realistic judgment of the typical pattern, reasonably adequate when large numbers of such series are combined so that the benefits of offsetting errors are obtained.[19] A small improvement, especially in the case of such major investments as a whole new manufacturing or power plant, would be to let capital input rise for a short time after installation before it reaches its present initial level in order to take account of break-in time and the remedying of initial defects. However, such a change would not alter aggregate series much.

The time pattern for a single capital good within its own service life is much the same as that I show for all 100—except that the drop toward the end of service life is more abrupt[20]—if a capital good typically is well maintained until a decision is made to retire it, the decision to retire occurs because of obsolescence well before it would occur if wear and tear were the only consideration, and maintenance is cut back after a decision to retire is reached so that performance deteriorates sharply just before retirement. Tibor Barna found these conditions to be typical of plant and equipment used in British manufacturing [10], and I believe them also to be representative of much plant and equipment in the United States.

What happens to capital input if the original capital goods are replaced when they are discarded?[21] If each of the 100 were replaced by a new but otherwise identical good just as it was discarded, capital input would rise by 0.33 percent as each good was replaced, and if (contrary to the Winfrey distribution) all were simultaneously replaced after 20 years capital input would rise by one-third; this results from my 3–1 weighting of gross and net stock. The rise would reflect the better performance and lower maintenance cost of unused capital goods.[22] If replacement were by goods of new and improved design costing the same amount as the old type, the effect on the capital input series would be the same. But as the new goods entered production, output would rise more than if replacement had been by new goods of the old type. The difference is the contribution of the development of better capital goods which can be supplied at the same cost as the old, a contribution which I wish to ascribe to advances in knowledge.

The pattern of capital input within the actual service life correctly takes no account of obsolescence due to

17. See [19, p. 14] for the rationale, and the reasons different weights have been used in different studies. I use this method only for nonresidential structures and equipment; I do not use a capital input series to measure the contribution of dwellings to growth.

18. Comprehensive capital stock series are little affected by changing the distribution of discards that is assumed. Some type of distribution around the average service life is desirable, however, to prevent an annual gross stock series from incorrectly mirroring too exactly sudden changes in past gross investment.

19. In the United States aggregate data for nonresidential gross and net stock usually move so much alike that even a substantial alteration in the 3–1 weights assigned scarcely changes the capital input index.

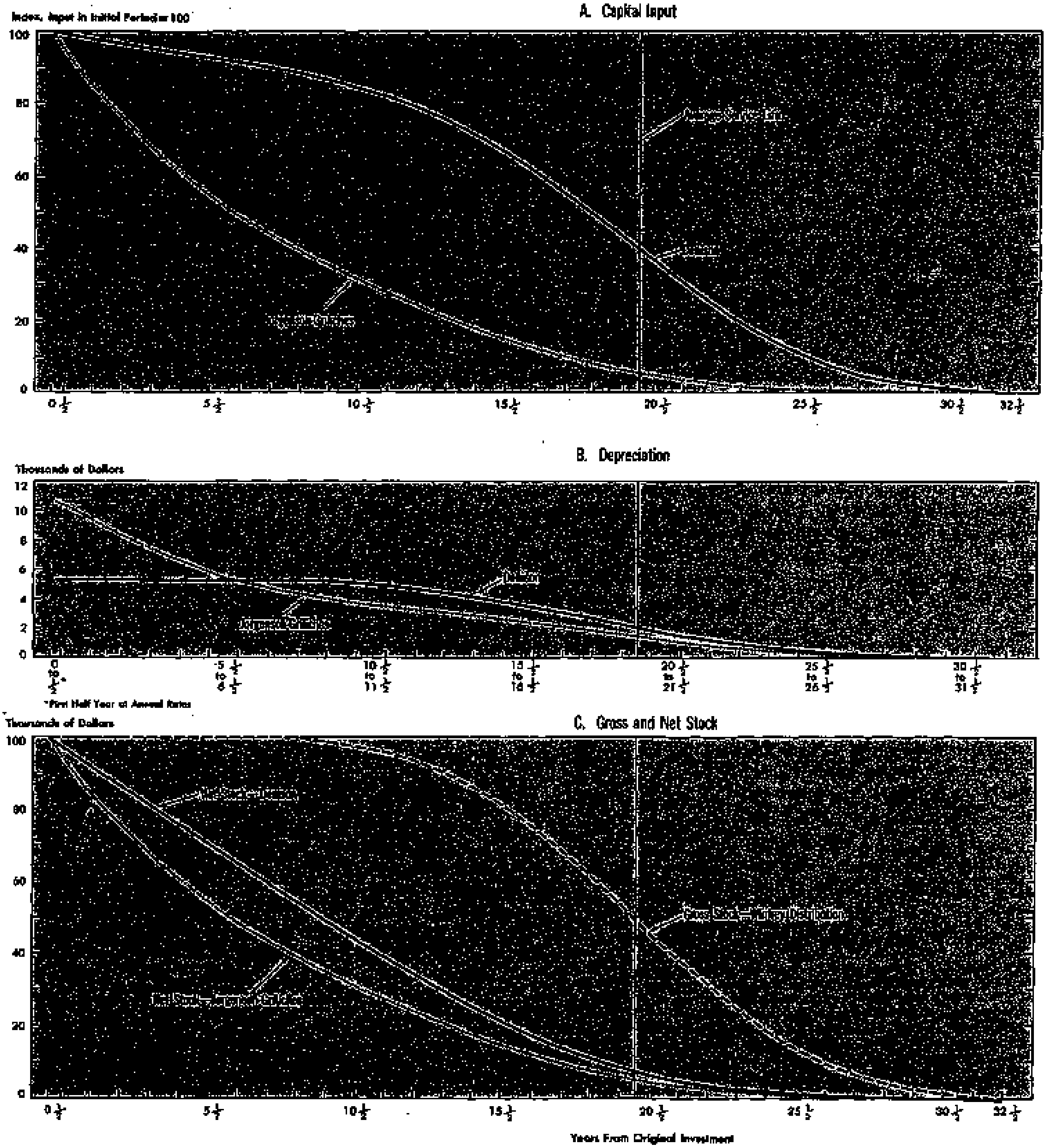
20. The tendency for abrupt decline is mitigated by the fact that some capital goods are used in a standby capacity before they are completely discarded.

21. I, of course, use "replaced" with its ordinary meaning.

22. Replacement by identical goods would not actually happen after an average of 20 years under the terms of the example because, if the original capital goods were to be replaced by identical ones, the original ones would be continued in service longer—for an average of 30 years; replacement occurs at the end of 20 years, on the average, only because better goods have become available and made replacement profitable.

Chart 1. Time Patterns of Capital Input, Depreciation, and Capital Stock for 100 Capital Goods Costing $1,000 Each, With Average Service Life of 20 Years

Comparison of Denison and Jorgenson-Griliches Estimates



availability of better capital goods, which in no way reduces the ability of existing capital goods to contribute to output.

The Jorgenson-Griliches series for capital input (i.e., their "quantity of potential service flow") is the same as the value of the net stock at constant prices that is computed by use of the declining balance formula at double the straight-line rate.[23] They state (p. 70): "We must specify the relationship between the quantity of an asset acquired at one date and the quantity of the service flow of the asset at future dates . . . we have assumed that the service flow from the ith investment good declines geometrically over time." The rate of decline (μ), which of course is crucial, is equal to 2 divided by the average service life [21, p. 295; 22, p. 34].

The services that capital goods with a 20-year average service life perform are estimated to decline by 10 percent in the first 12 months, and by 10 percent of the remaining amount every succeeding 12 months. The services of capital goods are thus assumed to drop sharply in the early years of their lives, then slowly. When only half the average service life is reached, and nearly all the goods may be presumed still to be in use, capital input is estimated to be only 33 percent of its amount at the beginning. When the average service life of 20 years is reached, capital input is estimated to be only 6 percent of its initial amount even though about one-half of the goods are still in use[24] and even though the reason that the average service life is not longer is commonly obsolescence rather than physical exhaustion. For short-lived goods the immediate reduction in services that is implied by the method is very extreme: for equipment with a 5-year average service life as shortened by obsolescence, it is 40 percent in the first 12 months. When one good is replaced by another at the expiration of service life, capital input jumps from almost nothing to the original value of the new good.

As I stated in my earlier article [19, p. 15], Jorgenson and Griliches assume that the ability of capital goods to contribute to current production drops very much faster and farther within their service lives than seems to me at all plausible. In my experience this judgment is widely shared. Why Jorgenson and Griliches use their pattern puzzled me then as it does now, and I am surprised that their present article neither makes any serious attempt to defend it (that some econometricians find it convenient is hardly expert testimony) nor abandons it. I can only leave it to the reader to judge which of the two patterns is the more reasonable on the basis of his own observation or experience.

Depreciation deduction to secure net product

This section will examine the first of the allegations that my estimates contain an inconsistency which those of Jorgenson and Griliches avoid. It will also consider which of our depreciation series is more reasonable for net product measurement.

Jorgenson and Griliches claim that the depreciation series I deduct from gross product to obtain net product is is inconsistent with my measure of capital input (pp. 65, 82, 86).[25] They recommend that in order to achieve consistency I use the declining balance formula to measure capital input, as they do, and also to measure depreciation (p. 87). Adoption of the latter recommendation would substantially raise my depreciation series and lower my net product estimates.

I have no desire to be consistently wrong, so I would be prepared to forego consistency if it could be obtained only by adopting capital input estimates which, as already indicated, I regard as unreasonable.[26] The situation, fortunately, requires no such choice.

Only the constant-dollar net output series enters the productivity calculations so only the constant-dollar depreciation series is relevant to this first allegation of inconsistency. To discuss it, I first describe the alternative depreciation series for the derivation of net product. Mine is computed by the straight-line formula. Jorgenson and Griliches recommend use of the double declining balance formula (p. 82). Chart 1(B) shows the two depreciation series for the example. They have two things in common. First, over the whole period the sum of annual depreciation charges in constant prices equals the cost of the asset in constant prices. Second, in constant prices depreciation in any period is equal to the change in the value of the net stock over that period, computed by use of the same formula. However, the two depreciation estimates in any period are very different. Theirs is higher in the earlier years and lower in the later yeas. The corresponding net stock values are compared in chart 1(C). The Jorgenson-Griliches net stock estimate is always lower than mine except at the installation date, when the two are the same. Aggregate depreciation for the economy is always higher by their method.

Because of disagreement as to just what the depreciation series deducted to obtain the net product of the nation is intended to measure (disagreements center on discounting and obsolescence), at least two views need to be considered in order to examine the issues.

The first view, to which I adhere, is that the best *implementable* procedure would be to obtain depreciation by allocating the cost of each asset over its service life in proportion to its estimated input at different dates.[27] My

23. The net value of a capital good would never drop to zero if this formula were applied literally but in practice some cutoff date must be used because gross capital formation data are not available for the infinitely remote past. OBE's procedure followed in the series plotted in chart 1 is to drop the remaining value when it is completely trivial.

24. Jorgenson and Griliches do not distinguish the reduction in input caused by discarding from the reduction caused by deteriorating performance of goods remaining in the stock, but it must be assumed that the implied pattern of discarding is consistent with the actual average service life from which the calculation starts.

25. The exact nature of this alleged inconsistency, as they see it, I cannot decipher because each time they discuss it, and particularly on p. 82 where their discussion is most extended, they misrepresent my depreciation series as an estimate of "replacement," which is it not by either the usual meaning of the word or their special meaning.

26. Jorgenson and Griliches could make their capital input estimates somewhat less unrealistic, while retaining the declining balance formula and its alleged advantage in convenience, by greatly reducing the value of μ.

27. As explained in footnote 21, this procedure differs from that which I would regard as theoretically best only in that obsolescence is spread over the life of the asset instead of charged when it is discarded.

depreciation estimates closely approximate those which would be obtained by this method and those of Jorgenson-Griliches meet it.

I could apply this method exactly but it requires a great deal of work that is unnecessary because, given my pattern for capital input, this "capital input" method would produce depreciation estimates that are very close to those obtained by straight-line depreciation. To take a simple example, suppose that an individual asset lasts 4 years and its services behave as I suppose when I weight gross stock 3 and the "straight-line" net stock 1. The following results, expressed as percentages of the original value, are obtained by these two methods and the double declining balance method.

	Denison capital input	Straight-line	Double declining balance
1st year	27.7	25	50.00
2d year	25.9	25	25.00
3d year	24.1	25	12.50
4th year	22.3	25	6.25
5th and later years, total			6.25

By merely relabeling the "years" in this table "quarters of total service life," the table can be applied to a capital good with any service life. For the nonresidential capital stock as a whole and its broad components the actual percentages of service lives exhausted invariably fall well within the two middle quarters of service life. The difference between the "Denison capital input" and "straight-line" depreciation estimates is trivial within this range, much too small to warrant the laborious calculations required by the "capital input" method.[28] For all practical purposes the straight-line depreciation estimates are consistent with my capital input series.[29]

If the time pattern of capital input is measured by the net stock computed by the double declining balance formula, the time allocation of depreciation by the capital input method is necessarily the same thing as direct use of the double declining balance formula, whose results are shown in the text table. Accordingly, if the capital input method is accepted, the Jorgenson-Griliches estimates too are consistent.

Jorgenson and Griliches deny that my estimates are consistent. They take pride in their own identity and are apparently untroubled that it is obtained only by their unrealistic assumption about capital input.

But Jorgenson and Griliches do not share my view that for net product measurement it is appropriate to obtain depreciation by the capital input method, and I shall bring out the strange fact that if their view of what depreciation should measure is accepted the consistency between their capital input and depreciation series, which pleases them so much, need no longer hold.

The second view, to which Jorgenson and Griliches adhere, is that the depreciation to be deducted to measure net national product should be the same as would be appropriate for business accounting for profits: it is the change that takes place during a year in the discounted value of expected future earnings of the asset.[30] Expected future earnings are governed by the number of years of remaining service life, and by the present value of each remaining year as it is affected by discounting future earnings to the present, by physical deterioration, and by obsolescence.[31]

Although I cannot accept this view, the choice between the two views seems to me to be of no great practical importance because I think the straight-line formula yields results that correspond better to those needed to account for *profits themselves* than does the double declining balance formula, and would therefore be the more appropriate of the two for computation of depreciation to secure net product even if the two series should be the same.[32] Let us explore the considerations.

The decline that takes place in the net value of an asset each year results from deletion of the present value of one year of remaining service life. Each year of life has an equal present value if (a) the discount rate is zero, (b) the good is of the one-hoss shay type so that there is no change in its physical ability to provide services throughout its service life, and (c) there is no actual or anticipated obsolescence. Under these conditions the exhaustion of every year of service life would reduce net value by the same absolute amount; the decline in value would be the same each year. The straight-line depreciation pattern clearly is appropriate in this case. But how does the pattern change if assumption (a), (b), or (c) is changed while the other two are retained?

A discount rate above zero makes the nearer years in the remaining life of an asset more valuable than the later years. A year in the remaining life of an

28. For each vintage of each separate category of structures or equipment, it requires a separate calculation for goods that are estimated by the Winfrey distribution to be discarded at each date.

29. The series for capital input themselves result from an assumption that, though realistic, is merely an approximation, and one should seek no greater precision from a depreciation estimate.

30. Presumably a constant discount rate is to be used for the life of the asset.

31. In my view, as already stated, net product measurement calls for the application of different criteria to the measurement of depreciation from those used in business accounting for profits. First, although it is correct to discount future income in computing depreciation to account for profits, it is not correct to do so in computing depreciation to obtain net national income or product, series in which every year is regarded from the standpoint of that year, not from the vantage point of some earlier year, and which include interest costs as well as profits [6, pp. 244–48; 9, pp. 281–82]. Second, obsolescence should be deducted when a good is retired rather than be spread over the good's service life. (If the capital stock is growing, this would yield lower estimates of aggregate depreciation in any year than the "capital input" method I have described as the best implementable method.) Even when a good is retired (although this point does not affect the numbers at all), obsolescence should not be thought of as a deduction from the value of the old good but as an offset to the value of the new, improved good which replaces the old good before its physical service life is exhausted [6, pp. 242–45]. (If there is no obsolescence it will not be prematurely discarded.) To deduct obsolescence at retirement, one would need to know the amounts by which obsolescence shortens service lives. In the total absence of such information, the best expedient is to spread obsolescence over the actual service life in proportion to capital input, the procedure adopted in the foregoing text table.

There are still other views on the appropriate measurement of depreciation for net output measurement. One, expressed by Richard Ruggles and at one time (though later withdrawn) by Simon Kuznets, differs from mine only in holding that no deduction at all for obsolescence is appropriate [3, pp. 469–70; 2, pp. 65–67; 7, pp. 277–79]. I presume this is a theoretical point because Ruggles did not explain how he would isolate obsolescence.

32. There are, of course, reasons to favor use of double declining balance in business accounting that are not pertinent here. Besides the fact that the double declining balance formula may appeal to business because it yields tax advantages and to others because allowing its use may stimulate investment, its popularity stems in part from the fact that in a period of sustained inflation its use offsets, though very imperfectly, the understatement of depreciation which results from use of original cost values. This is not a relevant consideration when, as in both the Jorgenson-Griliches-Christensen estimates and mine, depreciation is valued consistently at either current or constant cost.

asset that is 20 years in the future has less present value than a year immediately ahead—only one-third as much if the discount rate is as low as 6 percent. Shortening the remaining service life of a 20-year asset from 20 years to 19 years therefore deducts much less than 1/20 from its value. With discounting, the exhaustion of the first year of life is of the least value; the appropriate depreciation charge is small at first and steadily rises. The appropriate curve for net value is convex to the origin, the opposite of the declining balance pattern. The degree of convexity is greater the longer the asset's service life and the higher the discount rate. At any realistic discount rate the convexity is pronounced except for quite short-lived assets. For long-lived assets such as houses or other structures it is extreme. For example, assets with a 60-year life that meet conditions (b) and (c) would not lose half their value until they are 45 years old even if the interest rate were as low as 4 percent.

Deterioration of physical services works the other way; it makes the year of an asset's service that is used up each year more valuable than the average remaining year. However, if the typical pattern is at all as I suppose, the effect on depreciation is small, at least until the very end of an asset's service life is near.

Obsolescence also makes the later years less valuable. As it ages the asset must compete with better, newer goods simultaneously in service and this reduces its earnings. How important this is depends on the amount and timing of obsolescence that takes place within the good's service life. Both deterioration and obsolescence tend to make the pattern of net asset values concave.

Use of the straight-line formula in accounting for business profits assumes the effects of discounting to be approximately offset by those of deterioration and obsolescence, so that as a year is dropped from an asset's remaining service life its net value declines by the same percentage as does the number of years of remaining life or (what is the same thing) by the same absolute amount each year. If this assumption is correct—and it seems to me as reasonable as any alternative—the inconsistency between my capital input and constant price depreciation series that Jorgenson and Griliches allege is not present even by their criteria for measuring depreciation.

Insofar as Jorgenson and Griliches make any attempt to defend use of double declining balance, it rests on the alleged pattern of asset values. Use of a declining balance pattern for asset values assumes that the effect of discontinuing is *more* than offset by the effects of deterioration and obsolescence. Use of the declining balance formula at *double* the straight-line rate assumes that discounting is far more than offset. It implies either extremely fast deterioration of physical services or an extremely high rate of obsolescence. Jorgenson and Griliches do not say which they assume. If it is the former I can only repeat that so fast a pattern of deterioration strikes me as utterly unreasonable. More reasonable defenses of the use of double declining balance to measure net value of assets have rested on the proposition that obsolescence is very fast. This argument may well be valid for certain kinds of machinery which have been recently invented and are being rapidly improved. But even if double declining balance described the general pattern of asset values, and if the pattern were due to obsolesence being a much more potent factor than discounting, this would not mean that the double declining balance method would be appropriate to measure *capital input*. Because its pattern should not reflect obsolescence, capital input should decline much less rapidly than asset values. Use of the double declining balance formula for both capital input and depreciation is then *inconsistent*. The fact is that there is no way to be sure whether or not a capital input series and a depreciation series are consistent if one accepts the "second view" of what depreciation should measure unless one knows all the facts about discounting, deterioration, and obsolescence.

So much for this first charge of inconsistency. Let me return to the more interesting question of what probably does happen to asset values as capital goods age. In my opinion, the rate of obsolescence for structures and equipment as a whole that would be required to justify general use of double declining balance depreciation in accounting for business profits far exceeds any likely rate. To appraise the probable implications of the two formulas for obsolescence, an example, based on use of assumed illustrative numbers for the first year of life of an asset with a 20-year service life, may be instructive.

(1) If each year of its life is assigned the same value, as would be the case with no discounting, deterioration, or obsolescence, the loss of value (depreciation) in the first year is 5 percent.

(2) But it is necessary to allow for discounting. Assume an 8 percent interest rate. At that rate an annuity of 19 remaining future annual payments of equal amount is worth only 2.2 percent less than an annuity of 20 remaining payments of the same amount. Allowance for discounting consequently cuts the initial 5 percent first year depreciation to only 2.2 percent (or by 2.8 points).

(3) If there is deterioration, the first year's services represent more than 5 percent of the total services provided in the 20-year life span. For example, my method of measuring capital input would assign 5.7 percent, or 0.7 points more, to the first year. Moreover, the latter figure must be raised to take account of the fact that these extra services are more valuable because they occur in the first year than they would be in an average year of the 20-year period. At 8 percent, the 0.7 must be raised to 1.3.

(4) By adding to the 2.2 percent obtained in step (2) the 1.3 obtained in step (3), we obtain first year depreciation of 3.5 percent of total value. At first sight this would appear to be the appropriate first year depreciation before allowing for obsolescence. But this figure already includes an allowance for obsolescence unless the service life with which we started was not shortened by obsolescence. I have no information as to how much service lives are actually shortened by obsolescence on the average. I assume for this calculation, as I did in the example upon which the charts are based, that it was from 30

years to 20. In that case, the calculation should have started in step (1) with a figure of only 3.3 percent of original value instead of 5 as first year depreciation in the absence of discounting, deterioration, or obsolescence. This is a reduction of one-third, and the figure of 3.5 percent at which we have arrived up to now must be similarly reduced, to 2.3 percent, to obtain the first year depreciation appropriate in the absence of obsolescence.[33]

(5) The straight-line method charges 5 percent of original value in the first year, and thus on the assumption of this calculation allows for a rate of obsolescence of nearly 3 percent a year (5.0—2.3). The double declining balance method charges 10 percent in the first year and thus allows for a rate of obsolescence of nearly 8 percent a year (10.0—2.3). If the percentage rate of "unmeasured" quality improvement in capital goods is constant, then this rate—the annual percentage increase in the average quality of capital goods over and above that obtained by purchasing more costly capital goods—is the same as the rate of obsolescence. Thus, the two formulas imply about 3 and 8 percent, respectively, as the rate of unmeasured quality change.

These results depend on the terms of the example, but these were selected to be fairly representative and give a reasonable approximation of the situation for all structures and equipment.[34]

There are at least two reasons, besides general observation, to believe that a figure of the order of 8 percent a year is far too high to be representative of unmeasured quality improvement in all structures and equipment. One is that the combination of such a rate with observed service lives would be grossly inconsistent with rational business behavior. If, in the case of assets with a 20-year life, new capital goods that were 8 percent more efficient than the *previous* year's goods had been when they were new became available every year at the same price as the old, the original capital goods should be discarded by the time half of their 20-year life had expired. In only 9 years new goods would be twice as efficient as those in the original vintage had been even when they were new. The second reason is that the rate at which productivity advances—whether one accepts my estimates or those of Jorgenson and Griliches—is insufficient to accommodate the contribution that would be made by such a rate of quality improvement.[35]

Can one check directly on the way values change as goods age? If original cost, current cost, and constant cost are the same, the net stock series corresponding to the concept of business accounting for profits would be similar to one which might in principle be constructed by valuing each item in the stock by the higher of (1) the price the present owner would have to be offered to induce him to part with it, and (2) the highest price any prospective purchaser would be willing to pay for it. For many reasons, the first price is typically the higher, as evidenced by the small fraction of capital goods that are sold in any year, but this is not always the case and some goods are sold.

One is tempted to try to draw inferences from the study of second-hand prices. But there are only a few commodities for which markets are wide and representative enough to permit this even to be attempted; most are customarily tied in use to others (which makes transfer costs high and design unsuitable in another use) or even immovable. Houses and certain types of transportation equipment or other mobile machinery like tractors are the most promising. Even in these cases care is required to take proper account of transfer costs, changes in guarantees and other terms as goods that are sold pass from new to used and become older, differences between the condition of goods retained by owners and those offered for sale, changes in the price of new items, the strength of demand, the difference between list or asking prices and transaction prices for new commodities, and other complications.

Jorgenson and Griliches appeal to second-hand market values for a few equipment items to support use of the declining balance formula to measure net stock. Even for these items they do not try to support the *high rate* of attrition that they assume. They mention some conflicting results but fail to notice important studies by Raymond Goldsmith, Paul Taubman, and R. H. Rasche. Goldsmith [1] obtained the very opposite of the double declining balance formula for what is by far the biggest capital stock component to which Jorgenson, Griliches, and Christensen apply this formula. Using data from the 1934 Financial Survey of Urban Housing, he found that houses, for which a service life of 50 to 60 years is usually used, retained half the value of new houses when they were 45 years old.[36] This implies that depreciation on houses rises sharply as they age, and a highly convex pattern for net stock. Taubman and Rasche obtained similar patterns for office buildings, another large component of the capital stock, and believe them applicable also to factory buildings [20]. The evidence of second-hand prices can be used more effectively to argue that the straight-line formula makes asset values fall too fast than that it makes them fall too slowly. Indeed, if the general pattern for structures is that found by Goldsmith, Taubman, and Rasche; and if one also considers that large components of "equipment" are not production machinery but items like furniture, or such items as trucks, on which there is little obsolescence; then it is hard to see how the overall decline can be more than linear even if that for production machinery is. Certainly the evidence lends no support to the very fast decline which the double declining balance formula yields.

33. The result depends, among other assumptions, on the rate used for discounting. It would be raised from 2.3 to 2.9 percent of original value if a 6 percent interest rate were substituted for 8 percent. However, Jorgenson and Griliches use 10 percent as the rate of return; its use would yield a figure lower than 2.3.

34. It is quite possible that they overstate the average extent to which service lives are shortened by obsolescence, but it is certain that 20 years understates the average service life; and changes in these two assumptions have offsetting effects.

35. This is not a new way of looking at the matter [see e.g., 17, pp. 149, 150; and 13, p. 786].

36. This is not a surprising result. In the absence of deterioration or obsolescence, discounting alone would cause houses to retain half the value of new houses after 45 years of service if their total life were 60 years and the discount rate 4 percent, or if total life were 55 years and the discount rate 7 percent.

It may be anticlimatic to point out that the growth rate of net product is barely affected by the way depreciation is measured. In a real economy like the United States in which the capital stock is growing, depreciation is, to be sure, persistently higher and net product lower in constant as well as current prices if the double declining balance formula is used. But comparisons show that the difference is so stable that, except in quite unusual periods, it scarcely affects the growth rate of real net product. For measurement of output growth, the choice of formula is of minor importance.

Weighting: Total property weight

For analysis of the sources of growth of net product, the fact that the double declining balance formula, which Jorgenson and Griliches recommend, yields larger depreciation estimates in *current* prices than does the straight-line formula which I use *is* important. Its use yields a smaller estimate of the net (after-depreciation) earnings of capital and land—much too small an estimate, in my opinion. It thus reduces the weight assigned to capital and land relative to labor in the calculation of an index of total input and lowers the estimated contribution of capital to the growth of net product.

The second Jorgenson-Griliches charge of inconsistency (pp. 65, 85, 86) is that the depreciation series I use to obtain net property earnings and therefore the weights I use to combine labor with capital and land are inconsistent with my capital input series whereas, they claim, their capital input and depreciation series are consistent with one another. Because there is no conceptual distinction between depreciation appropriate for the measurement of net product according to the "second view" and depreciation appropriate for use in measuring capital earnings to be used in weights (p. 86), my showing in the preceding subsection that their charge that my depreciation for net product measurement and my capital input are not inconsistent on the "second view" is equally a response to this second charge of inconsistency.

However, it may be useful to look at this charge in another way. It is apparently because in my estimates the ratio of (1) capital input to (2) the net stock that is consistent with depreciation rises as a capital good ages, whereas in their estimates it is constant, that Jorgenson and Griliches think my series are inconsistent.[37] This notion could hardly be more wrong. The ratio clearly should rise to reflect the reduction in the remaining years of service life; the only question is whether my ratio rises too much or too little. It rises by the correct amount if there is no discounting, obsolescence, or deterioration or if the effects of discounting on the net value of an asset just offset those of obsolescence and deterioration, the assumption underlying use of straight-line depreciation for this purpose. If discounting is not fully offset, my ratio does not rise fast enough. The direction or size of the error, if any, cannot be determined without exact data for the appropriate discount rate, for obsolescence, and for deterioration.

Failure of the Jorgenson-Griliches ratio of capital input to net stock to rise as the remaining service life of an asset diminishes is *prima facie* evidence that their series are inconsistent, not an indication of consistency. As I said in my earlier article [19, p. 15], "value must decline as remaining service life diminishes whereas a measure of current services must not do so" for this reason. If they insist upon using the declining balance formula, they should at least use a lower rate of attrition for capital input than for net stock.

Jorgenson and Griliches also assert that the depreciation series I use to obtain capital earnings and the depreciation series I use to obtain net product are inconsistent with one another; indeed, they call this the "most serious" problem with my treatment of depreciation (p. 85). This is an especially puzzling charge. Except that one is in current and the other in constant prices, my two depreciation series are the same.

37. At least, this is the only interpretation I can place upon this charge.

They should be the same if one believes, as they do, that the same criteria are appropriate for both depreciation series. If (as in my case) he does not, then the two should be the same only if the same measure conforms to both sets of criteria. I have argued above that the straight-line formula in fact gives the best approximation to both, and this is why I use the same series.

Although Jorgenson and Griliches find my two series, which are identical, to be inconsistent with one another, they find the two series they recommend, which also are identical, to be consistent with one another!

Weighting: Allocation of total property weight

Because the double declining balance formula used by Jorgenson and Griliches yields much smaller values for the net stock of structures and equipment in current prices than does the straight-line formula, without affecting land and inventory values, its use reduces (I believe understates) the share of the total capital and land weight (itself already reduced by double declining balance depreciation) that is assigned to structures and equipment, and raises the shares assigned to land and inventories. This is because asset values are used to allocate their total weight among these types of assets.

Let me now refer to what I take to be the last of the Jorgenson-Griliches charges of inconsistency in my estimates: that the allocation of my total weight for capital and land among detailed components is inconsistent with my measure of capital input (pp. 65, 75).

As I have stressed, the ratio of input to value rises as a depreciable asset grows older and fewer years of future service life remain. This fact does introduce a small error into my allocation of weights among nonresidential structures and equipment, inventories, and land. I shall describe this defect in a moment. It does not affect my weight for dwellings and residential land, and it is reduced by treating sectors, in which the proportions of the other three types of assets differ, separately in deriving weights.[38] It creates an "inconsistency" between my detailed weights and my capital input series in the same sense that any series which contains an error is inconsistent with any other series which does not contain the same error.

The aroma of discovery with which Jorgenson and Griliches disclose this error is surprising inasmuch as I pointed it out in my first growth study and have noted it repeatedly, even in the article to which Jorgenson and Griliches are responding [19, footnote 20, and references given there]. Only by producing a set of series which contain the basic inconsistency of implying a constant ratio of capital input to net stock value do Jorgenson and Griliches themselves avoid this inconsistency in detail.

38. In published studies the sectors are farm and nonfarm nonresidential business. My present study also divides the nonfarm component between corporate and noncorporate entities. These divisions are made only to improve the weights attached to structures and equipment, inventories, and land. Unlike the new Christensen-Jorgenson procedure described under the heading "Change in Classification of Gains from Reallocation of Resources," I do not treat capital or land used in different sectors as separate inputs.

The error is easy enough to describe. I wish to assume that the rates of return on inventories, land, and fixed capital within any sector distinguished are the same. Distribution of earnings in proportion to asset values (the statistical procedure adopted) implements this assumption exactly only if ratios of net earnings to net asset values correctly measure rates of return. For a depreciable asset, the ratio of net earnings to net asset value necessarily increases in the course of its service life and can be equal to the rate of return over the whole service life (the desired figure) at only one date. My procedure implies an assumption that for the whole nonresidential stock this point is reached when the fraction of service life that is exhausted is that which actually has been exhausted. Most rate of return estimates are similarly based on earnings-asset ratios, with the curious exception, as I pointed out elsewhere, of those concerned with human capital [17, p. 142].

For any category of capital goods, the fraction of the total service life that will have been exhausted when the ratio of earnings to asset value actually equals the rate of return depends upon the length of total service life, the rate of return, the time pattern of the good's contribution to earnings, the time pattern of capital input, and the amount and time pattern of obsolescence. In the absence of obsolescence, the estimated time pattern of capital input can be used to calculate just when this point is reached for capital goods of any stated service life at any stipulated rate of return, and I have often made illustrative calculations of this type. I have even tried to correct comparisons of rates of return in different countries, obtained initially as earnings-asset ratios, to allow for differences among countries in the fraction of service lives exhausted [17, pp. 142–43]. In the course of such experimentation, I have satisfied myself that the error introduced into my weights by use of the usual assumption is minor.[39]

39. It appears usually to cause slight understatement of the weight attached to structures and equipment and overstatement of that assigned to land and inventories. Use of the double declining formula would yield much greater understatement of the weight assigned structures and equipment, but the offset is in the labor weight.

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By DALE W. JORGENSON and ZVI GRILICHES

Final Reply

In our paper, "The Explanation of Productivity Change" [60],[1] we showed that earlier estimates of total factor productivity by Edward F. Denison and other productivity analysts contained serious conceptual flaws. Most analysts weight total labor and total capital input by estimates of their marginal products to obtain a measure of total factor input. We argued that the same principle should have been applied consistently to the subcomponents of labor and capital input as well.

In our paper, "Issues in Growth Accounting: A Reply to Edward F. Denison," we demonstrate in much greater detail that capital input and total factor productivity measures employed by Denison in his monographs, *Sources of Economic Growth . . .* [26] and *Why Growth Rates Differ* [28], are permeated by internal contradictions. Although Denison agrees that subcomponents of capital input should be weighted by their marginal products, he fails to apply this principle in an internally consistent way.

The force of our criticism is easy to appreciate, even for someone who does not wish to enter into the details of the argument. Economic depreciation plays a crucial role in any measurement of capital input and total factor productivity. Depreciation depends on the decline in efficiency of capital goods. In Denison's two monographs two different assumptions about decline in efficiency are employed, but the same basic method for calculating depreciation, the straight-line method, is employed in both.[2] At a minimum it is obvious that if one of Denison's calculations is correct the other is wrong. In our reply to Denison we demonstrate that both sets of calculations are internally inconsistent.

Denison's paper ". . . Major Issues . . ." [25] is devoted to an examination of our procedures for estimating total factor productivity in "The Explanation of Productivity Change" [60]. All of Denison's valid objections to these procedures have been met and several major improvements have been made in our new estimates, based on those of Christensen and Jorgenson [19, 20].[3]

Specifically, capital input has been disaggregated so as to incorporate the effects of direct and indirect taxation in a more satisfactory way. Second, our estimate of the effects of changes in relative utilization has been revised downward. As before, our conclusion is that total factor input, not productivity change, predominates in the explanation of the growth of output.

In our discussion of quality change we distinguish between measures of "quality change" which make it equal to one or another version of the "residual" tautologically, and quality change estimated from current differences in marginal products. To us, this latter type is "measured" quality change, provided that it can in fact be measured with some precision from observed market prices and rents of different commodity groups, including different vintages, and we would wish to count it as part of input in the capital-using sector. This procedure will not eliminate productivity change by definition since it will result in a higher productivity growth in the capital-producing sector. It will only attribute it where it belongs.

Various other issues raised by Denison deal with the semantic problem of what to include in "input" and what to include in "productivity." Since at the aggregate level the idea of an input is at best rather vague while the idea of "productivity" does not hide anything more than the "residual" from all the other calculations, it has been our tendency to take out most of the measurable sources of growth (such as intersectoral shifts) from the wastebasket of the "residual" and include them perforce in our concept of input. We have no objection, however, to a more complex classification scheme.

The major portion of Denison's "Final Comments" is devoted to defending the procedures used in *Why Growth Rates Differ* [28].[4] To state our criticism of these procedures as succinctly as possible: We do not insist that Denison adopt our assumption of geometric decline in efficiency, let alone our depreciation rates; this is one way of solving the problem of maintaining internal consistency, but it is not the only solution. We simply urge him to adopt a single assumption about decline in efficiency and to employ this assumption in measuring both depreciation and capital input. Denison's procedures in *Why Growth Rates Differ* [28] employ one assumption for depreciation and another for capital input.

Denison's defense of the methods employed in *Why Growth Rates Differ* fails to meet the basic issue of inconsistency. Unlike Denison's paper, his accompanying "Final Comments" do not really advance the discussion of the methods of measuring total factor productivity further. We are prepared to leave this exchange of views with Denison at this point and to proceed with the work of continuing to improve our estimates in both scope and quality.

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1. All reference numbers are from the list of references given in our accompanying paper, "Issues in Growth Accounting: A Reply to Edward F. Denison."

2. Here we adopt Denison's interpretation of his estimates, based on replacement, as measures of depreciation. Denison's two "views" of depreciation in his "Final Comments," pages 104–107, are definitions of two distinct concepts—*replacement* as defined on page 85 of our accompanying paper and *depreciation* as defined on page 88. Th· use of a single term for the two concepts is the source of Denison's error in the definition of net product and of inconsistencies in his accounting for depreciation and capital input. See our accompanying paper, "Issues in Growth Accounting: A Reply to Edward F. Denison," p. 88, for an elaboration of these points.

3. Denison's objections to our deflation of government and rest of the world product have already been met in a revised and extended set of estimates for the period 1929–1969; see: D. W. Jorgenson, "Measuring Economic Performance," in M. Moss (ed.), *The Measurement of Economic and Social Performance*, Studies in Income and Wealth, No. 37, New York, Columbia University Press, forthcoming. Preprints are available from the author.

4. See pages 89–109.

U. S. GOVERNMENT PRINTING OFFICE : 1972 O - 461-373